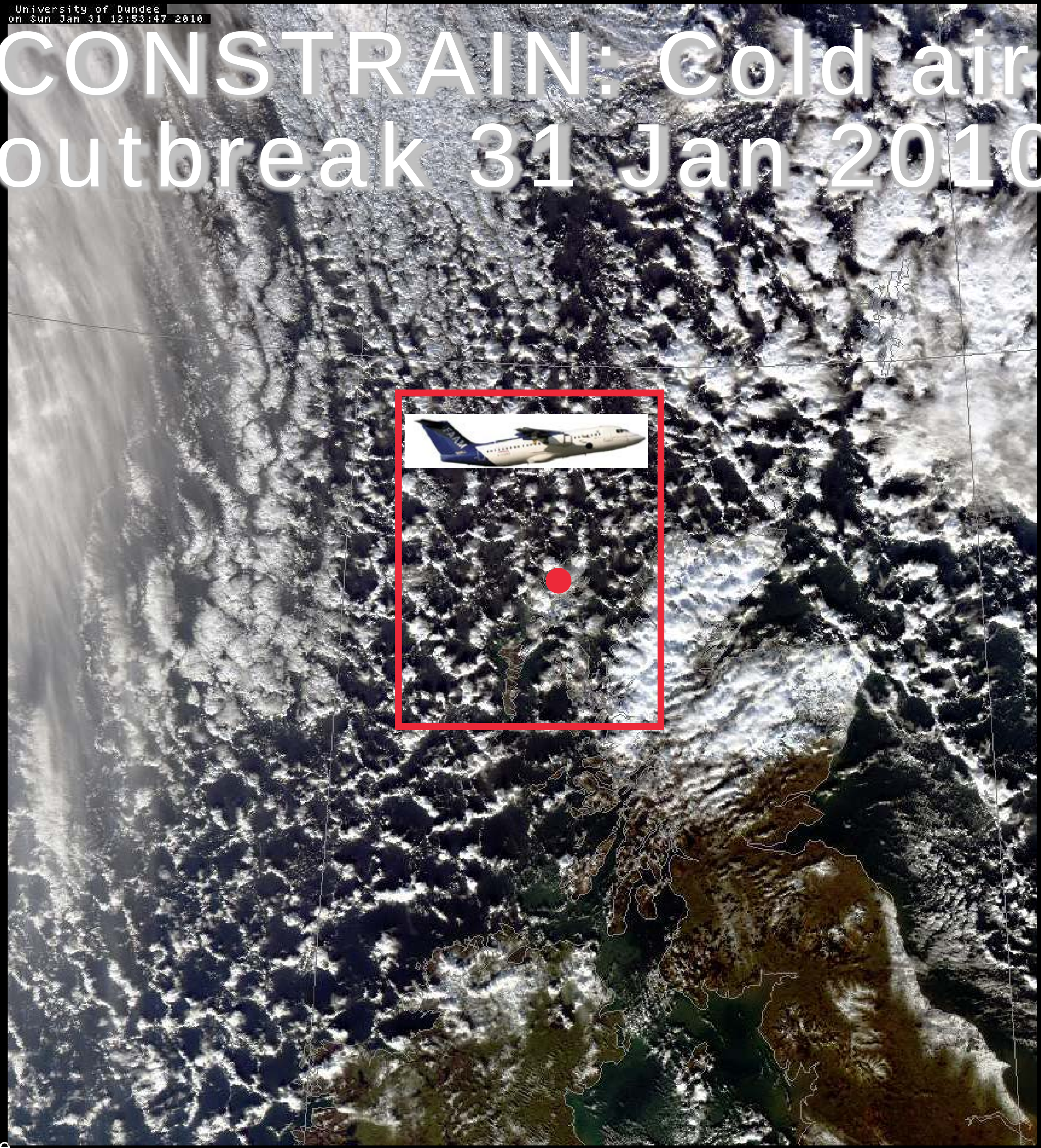
Mixed-phase

Paul Field

Richard Cotton, Adrian Lock, Kirsty McBeath, Richard Allen, Stuart Webster, Adrian Hill, Kalli Furtado, Alexei Korolev, Andy Heymsfield, Arron Bansemer.

CONSTRAIN: Cold air outbreak 31 Jan 2010



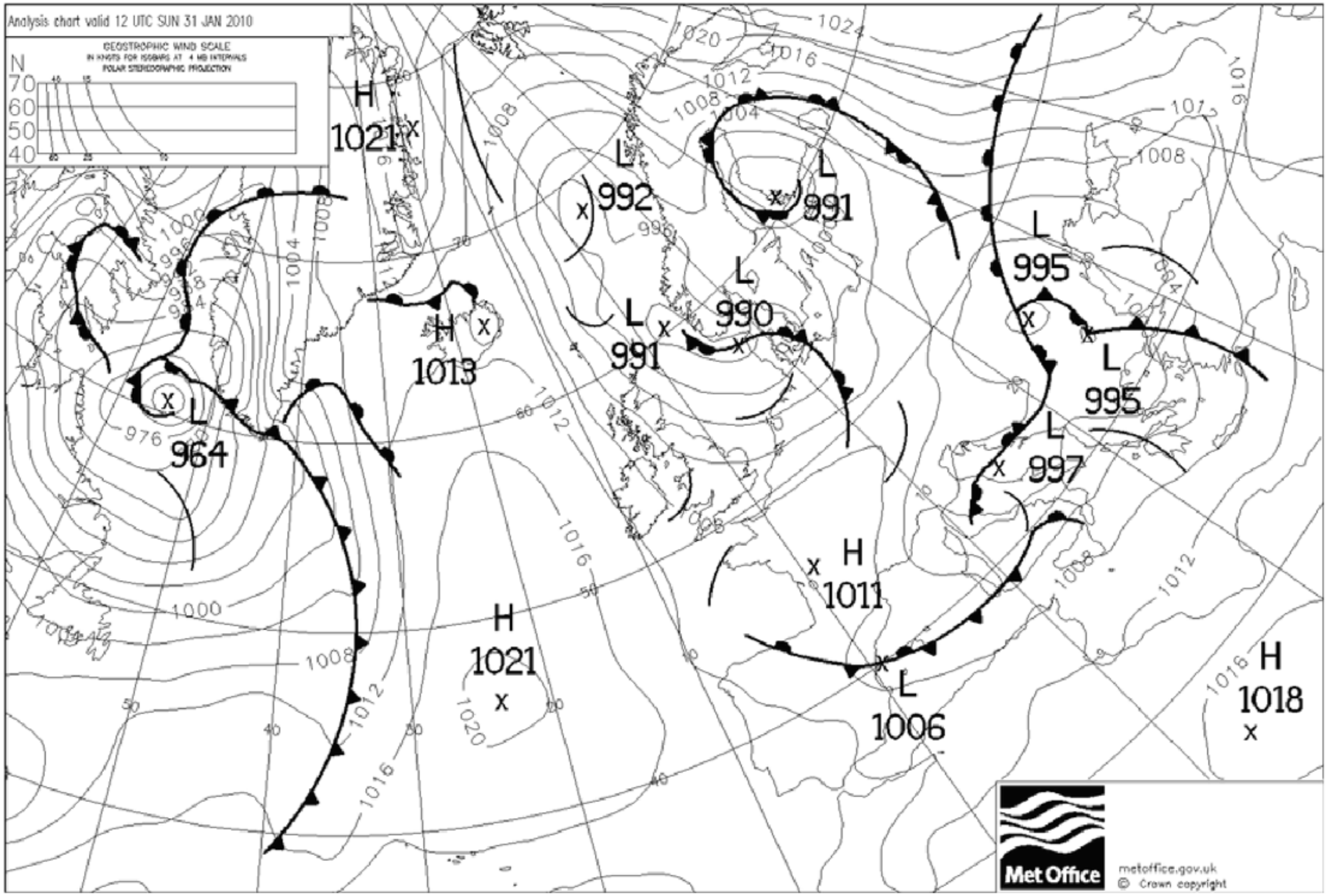
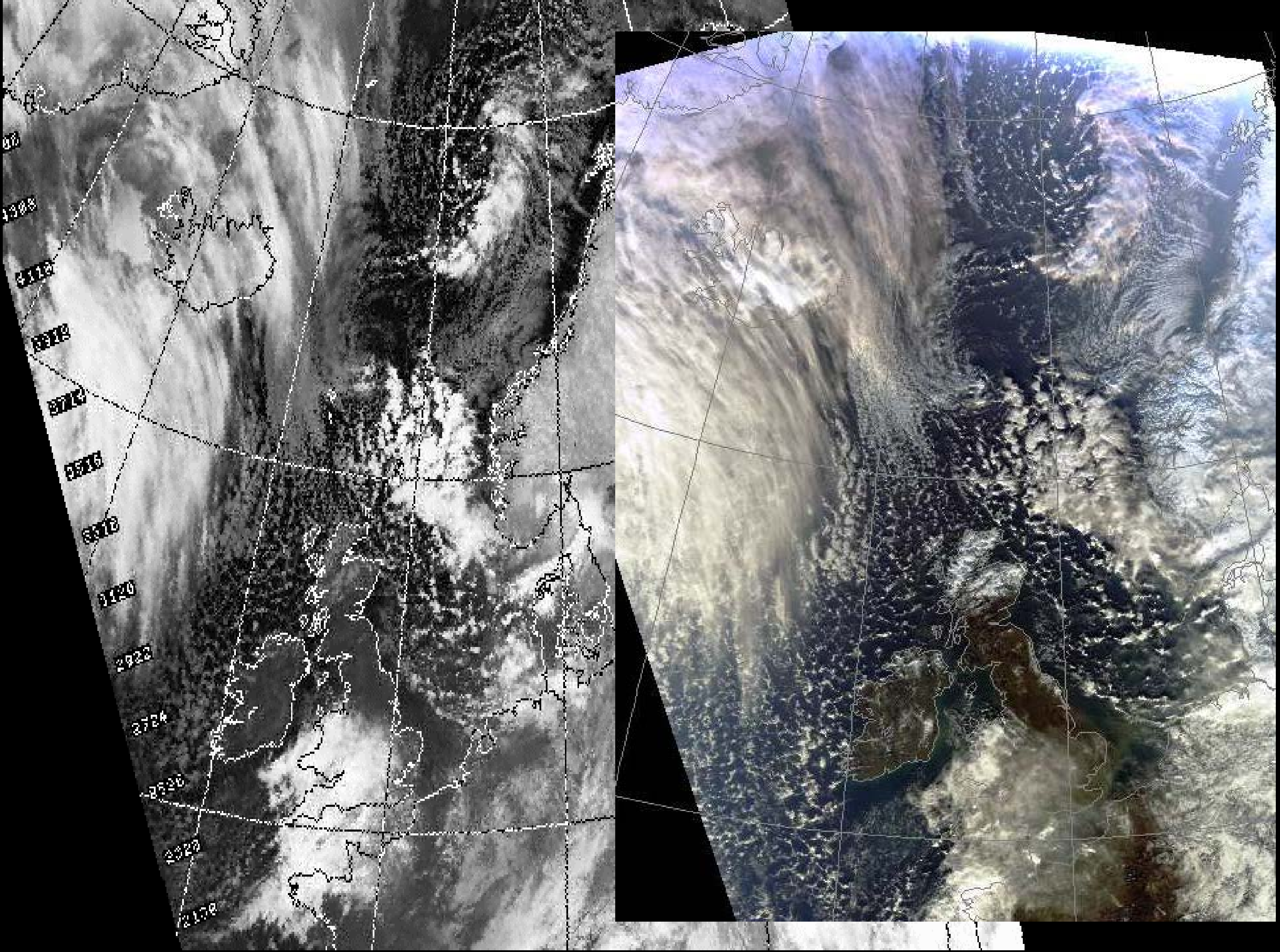
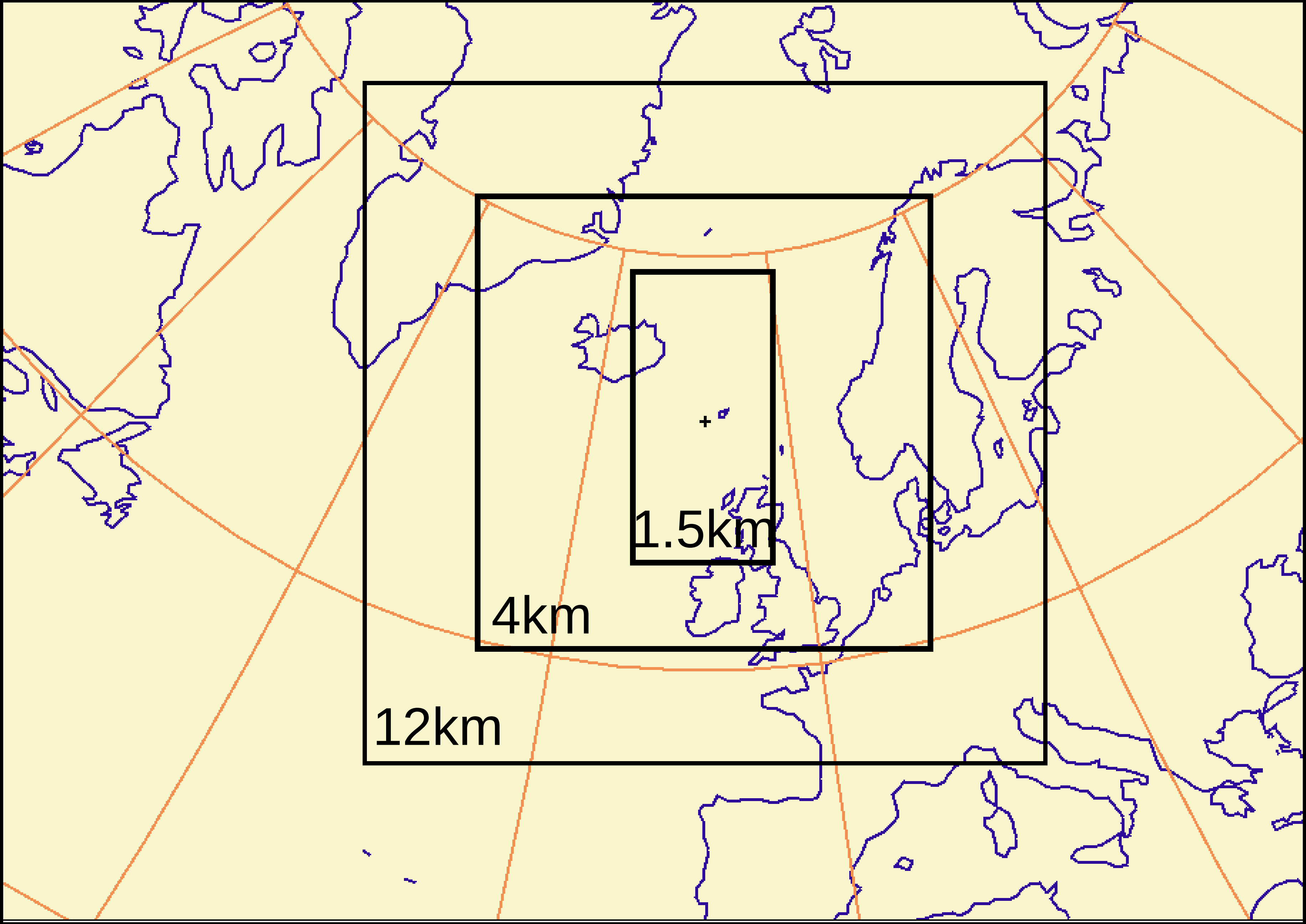
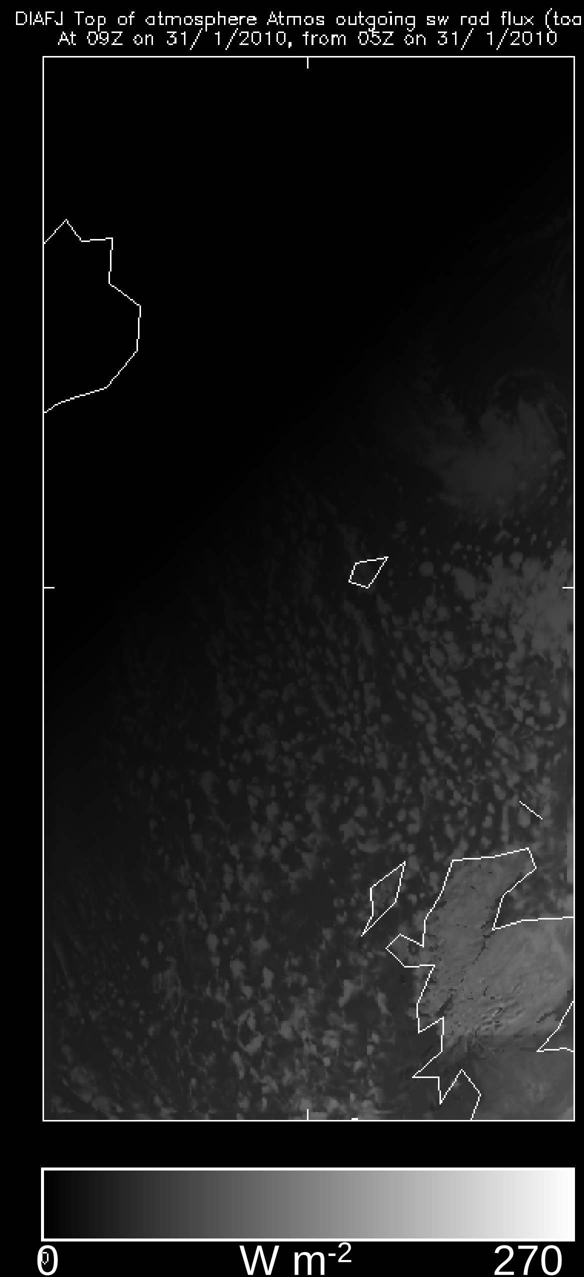
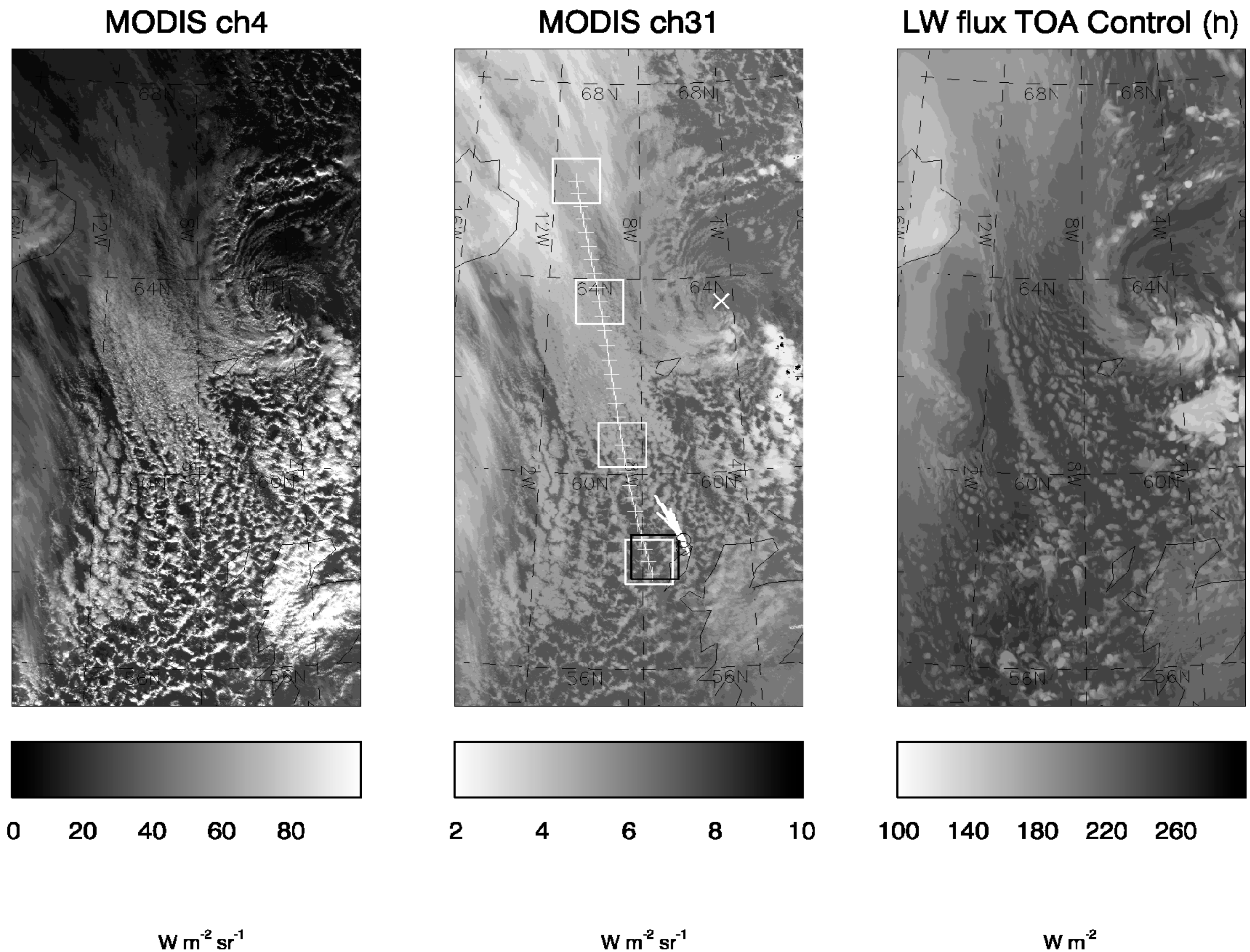


Figure 1. Analysis chart for 12 UTC 31st January 2010.

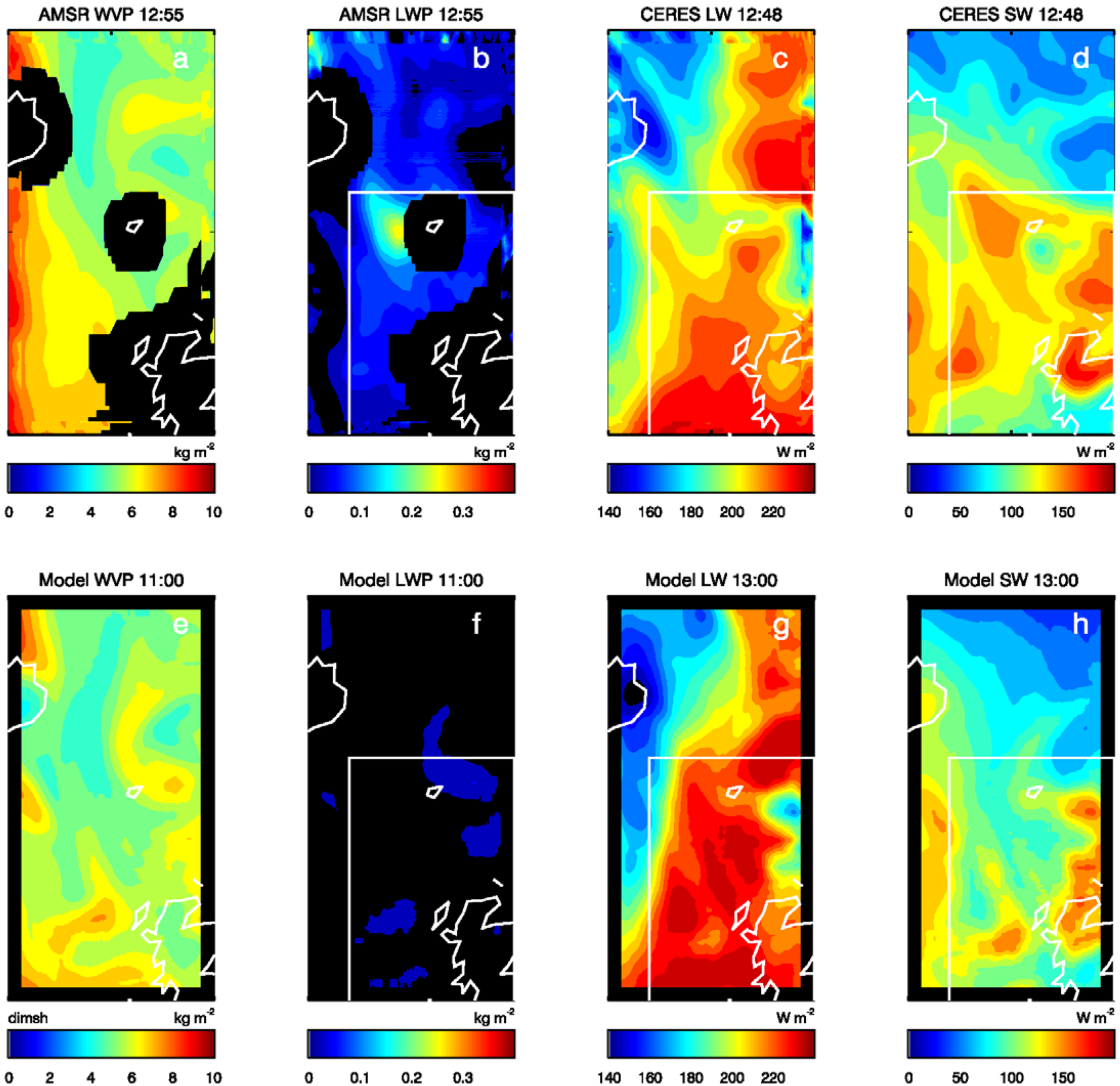



1.5km
4km
12km


DIAFJ Top of atmosphere Atmos outgoing sw rad flux (toa)
At 09Z on 31/ 1/2010, from 05Z on 31/ 1/2010
0
W m-2
270



MODIS ch4
MODIS ch31
LW flux TOA Control (h)
68N
64N
60N
56N
12W
8W
4W
0
20
40
60
80
W m-2 sr-1
2
4
6
8
10
W m-2 sr-1
100
140
180
220
260
W m-2



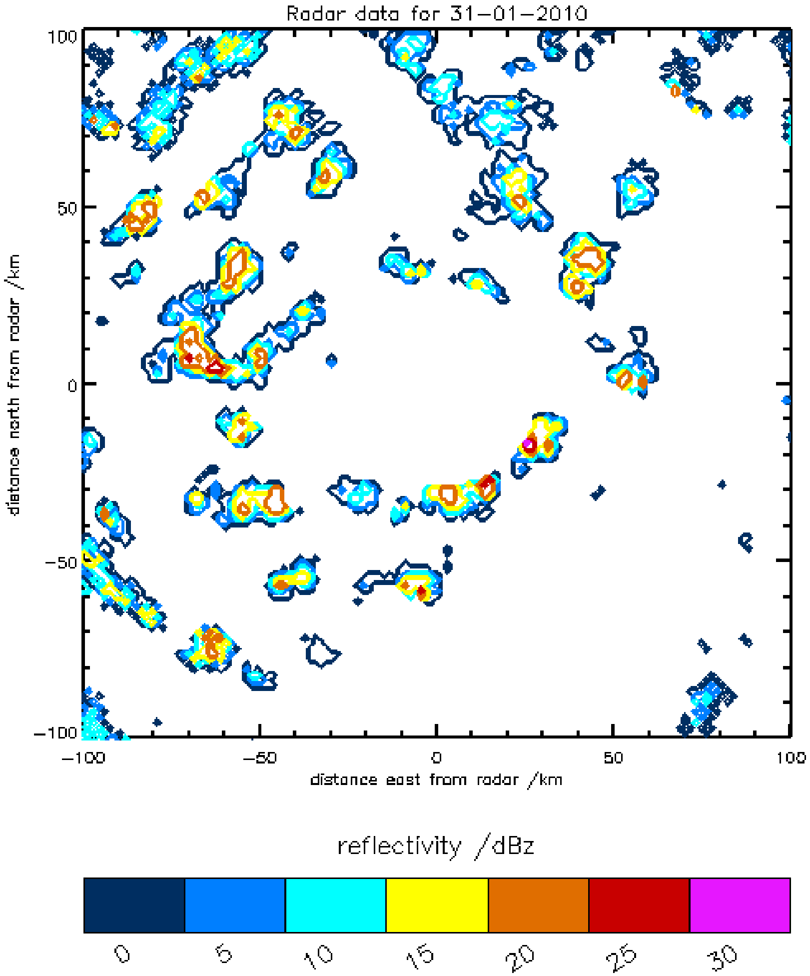
Microwave Obs

Control Model

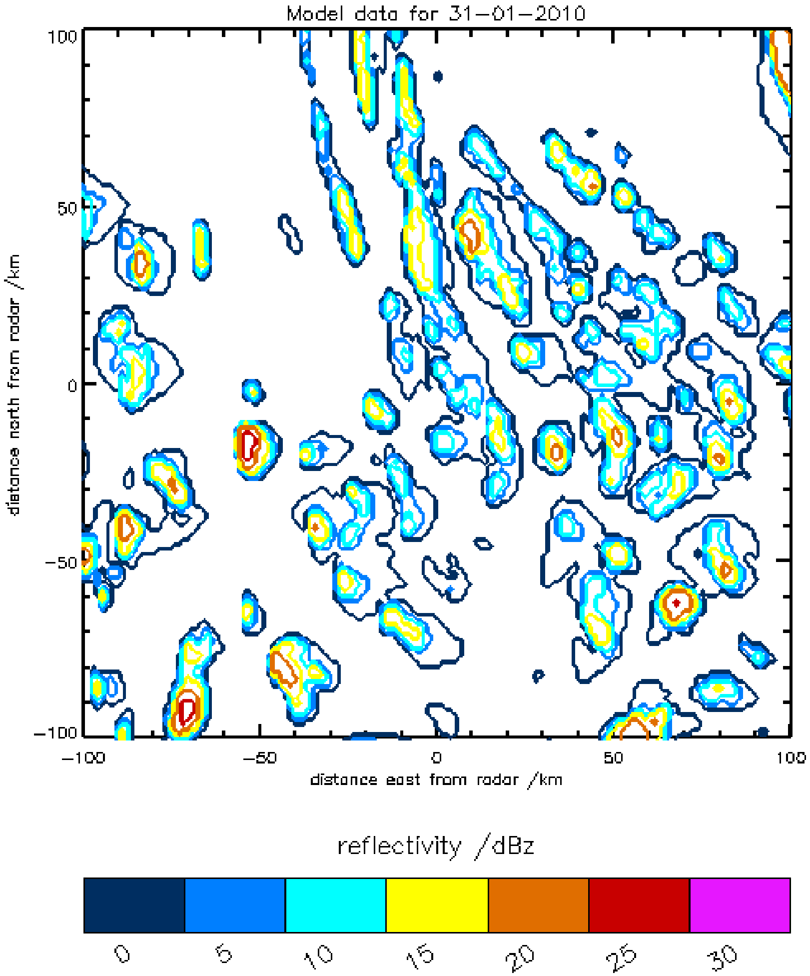
Kirsty McBeath

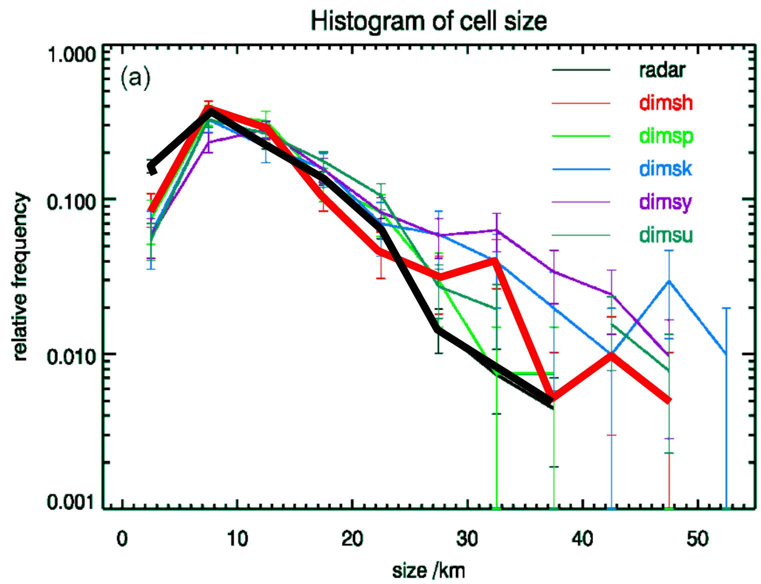
Reflectivity values for UM computed using model microphysics data, this reduces processing done on radar data and removes assumptions used when converting reflectivity to rain-rate

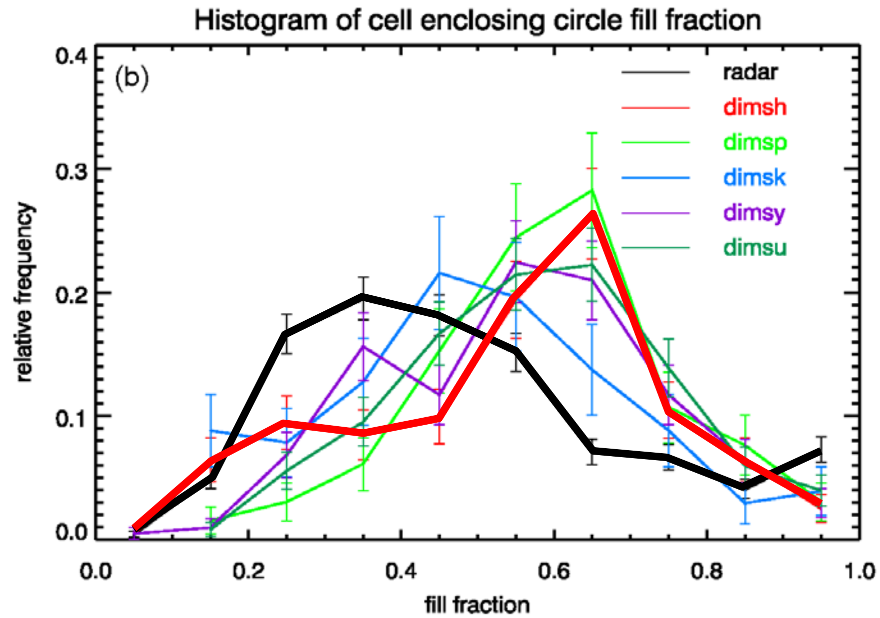
Radar

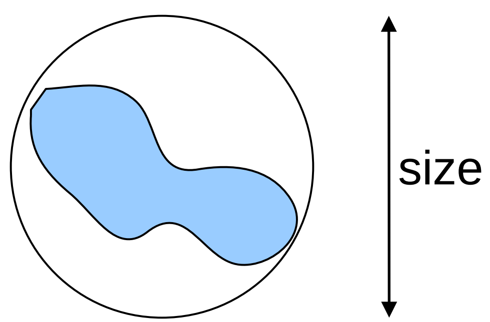


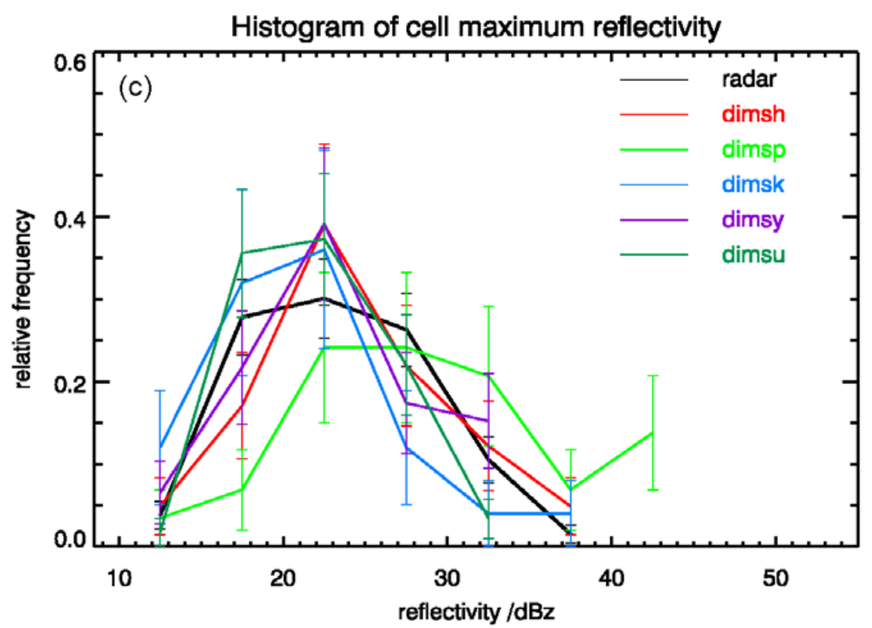
Model




Histogram of cell size
(a)
radar
dimsh
dimsp
dimsk
dimsy
dimsu
relative frequency
1.000
0.100
0.010
0.001
0
10
20
30
40
50
size /km


Histogram of cell enclosing circle fill fraction
(b)
radar
dimsh
dimsp
dimsk
dimsy
dimsu
relative frequency
0.4
0.3
0.2
0.1
0.0
0.0
0.2
0.4
0.6
0.8
1.0
fill fraction


size

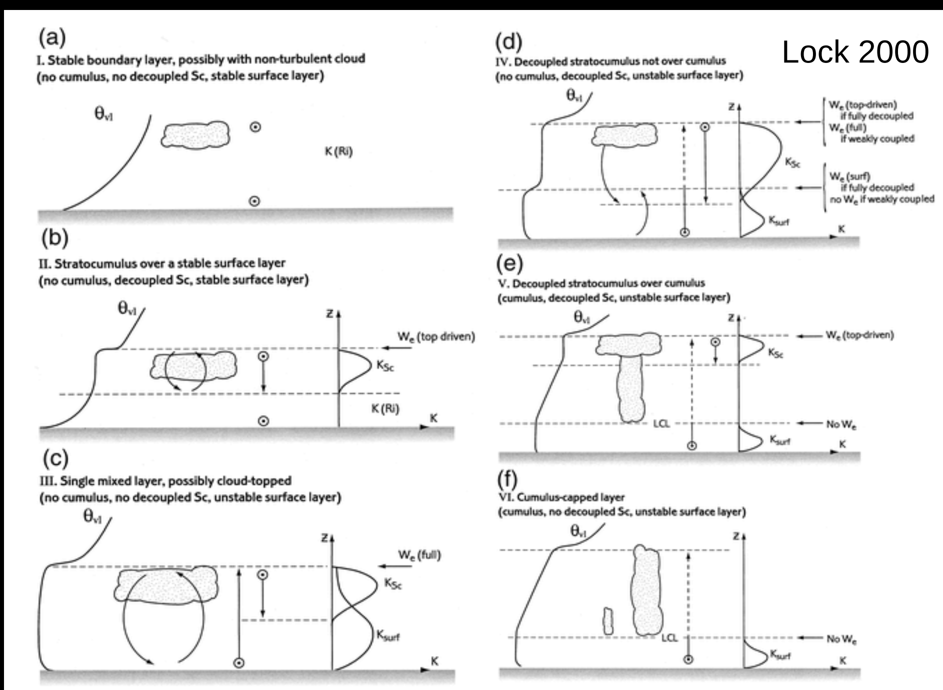

Histogram of cell maximum reflectivity
(c)
radar
dimsh
dimsp
dimsk
dimsy
dimsu
relative frequency
0.6
0.4
0.2
0.0
10
20
30
40
50
reflectivity /dBz

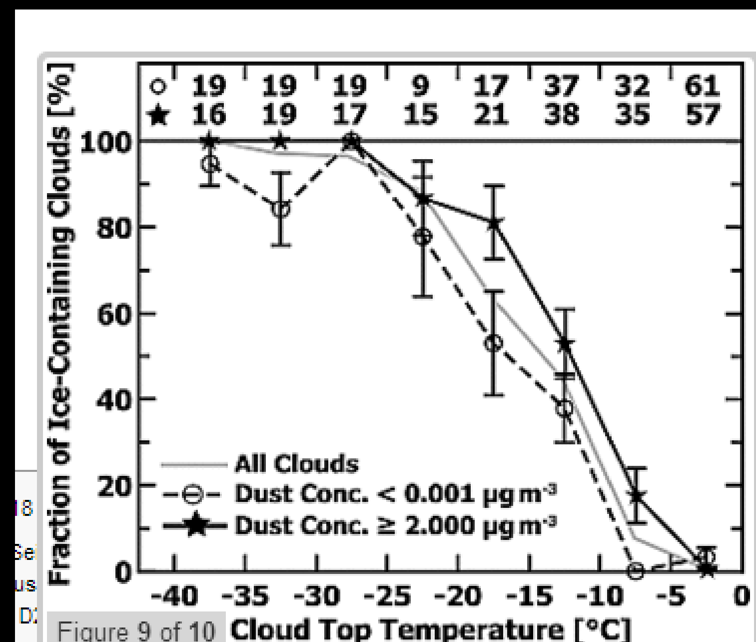
Main short comings of the control model:

Not enough cloud cover in the stratiform region

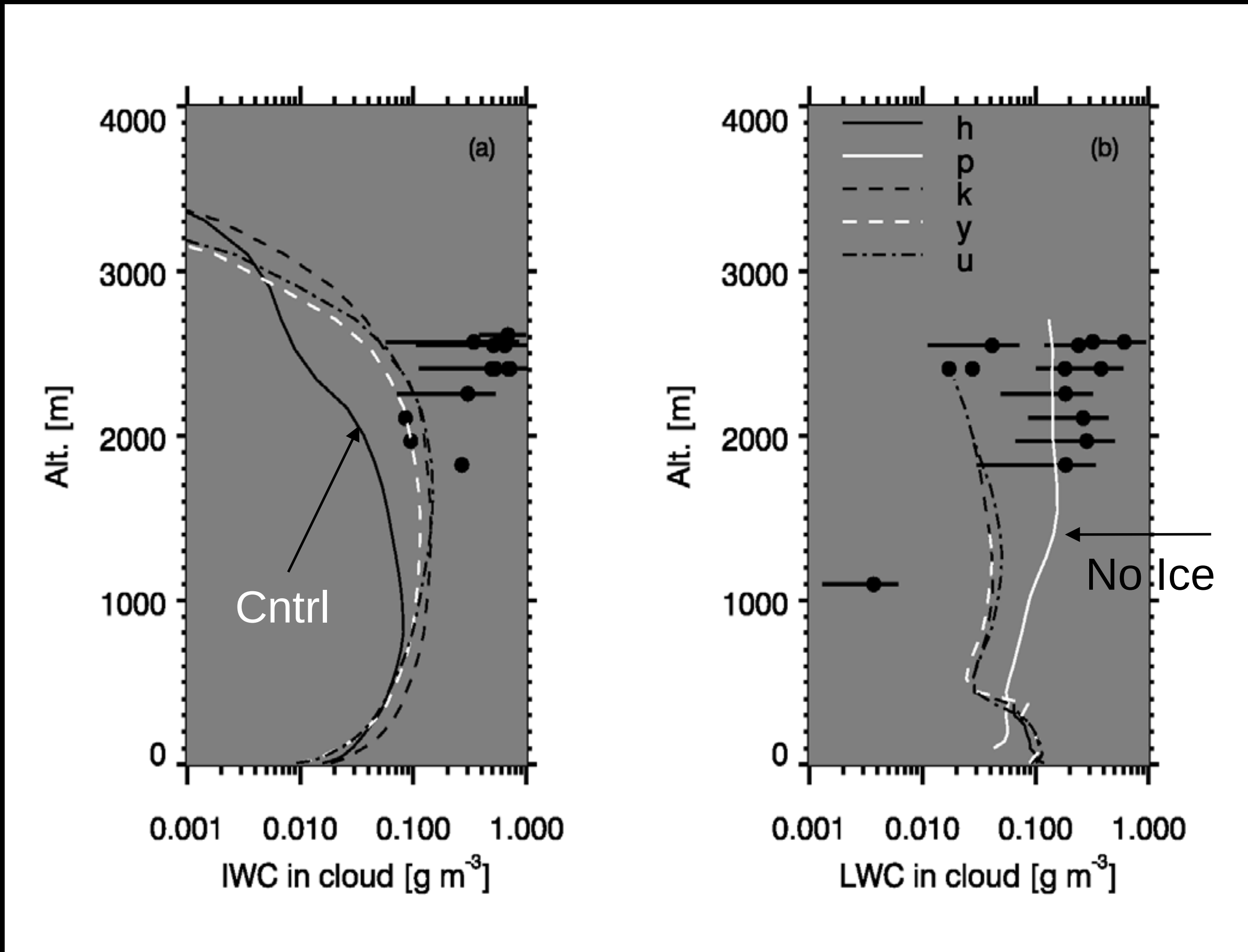
Not enough liquid water

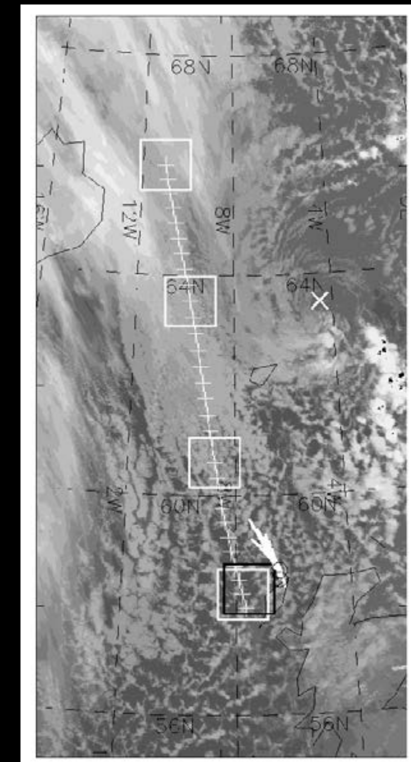
Experiment	Sh. dom. BL.	Tnuc=-18C	AcE=0.1	No ice	PSD	3dSmag
dims**h**						
dims**p**				✓		
dims**q**			✓			
dims**n**						✓
dims**k**	✓					
dims**i**	✓		✓			
dims**z**	✓	✓				
dims**y**	✓	✓	✓			
dims**u**	✓	✓	✓		✓	
dims**w**		✓	✓			✓



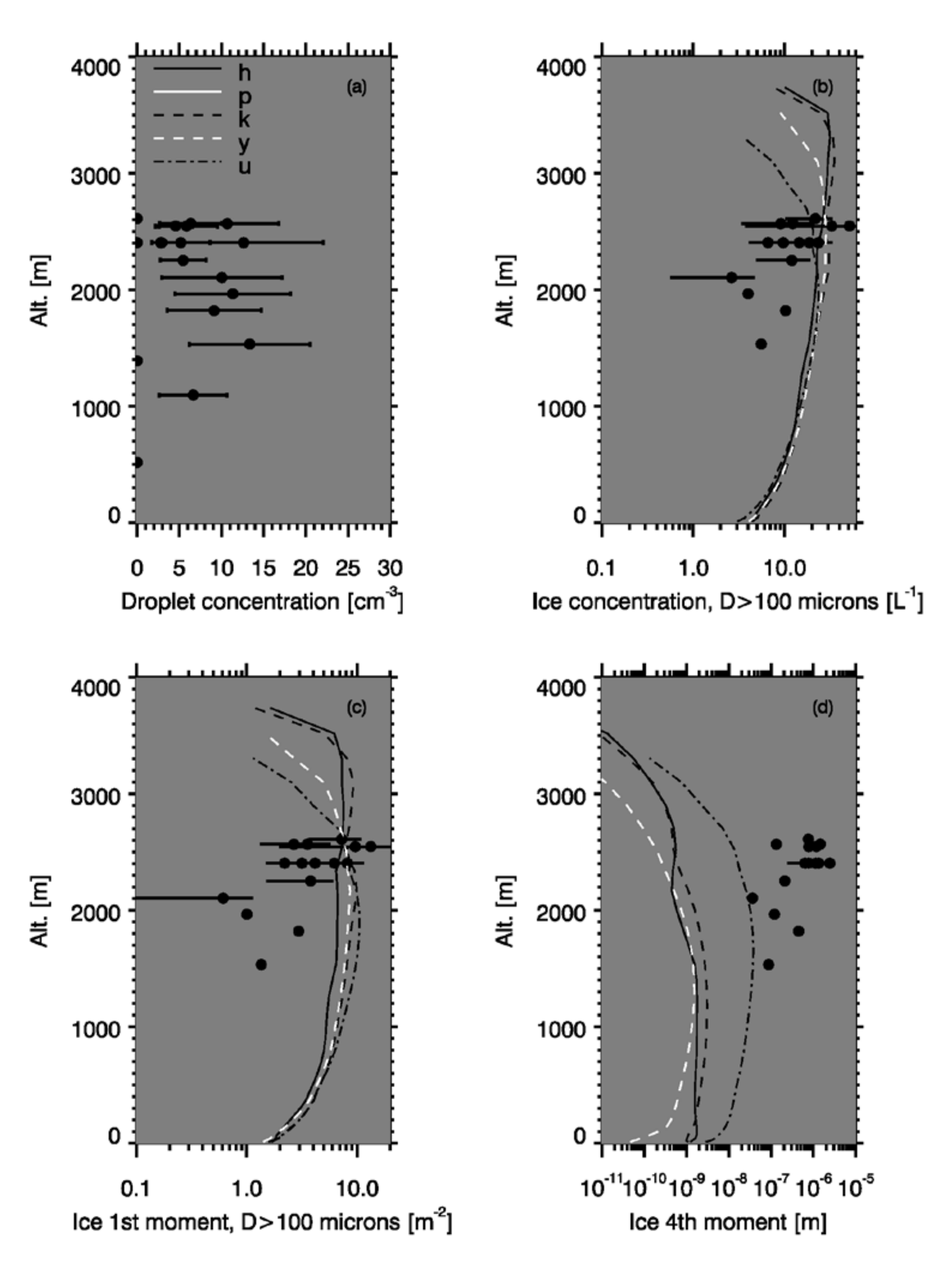


P. Seifert 2010 JGR

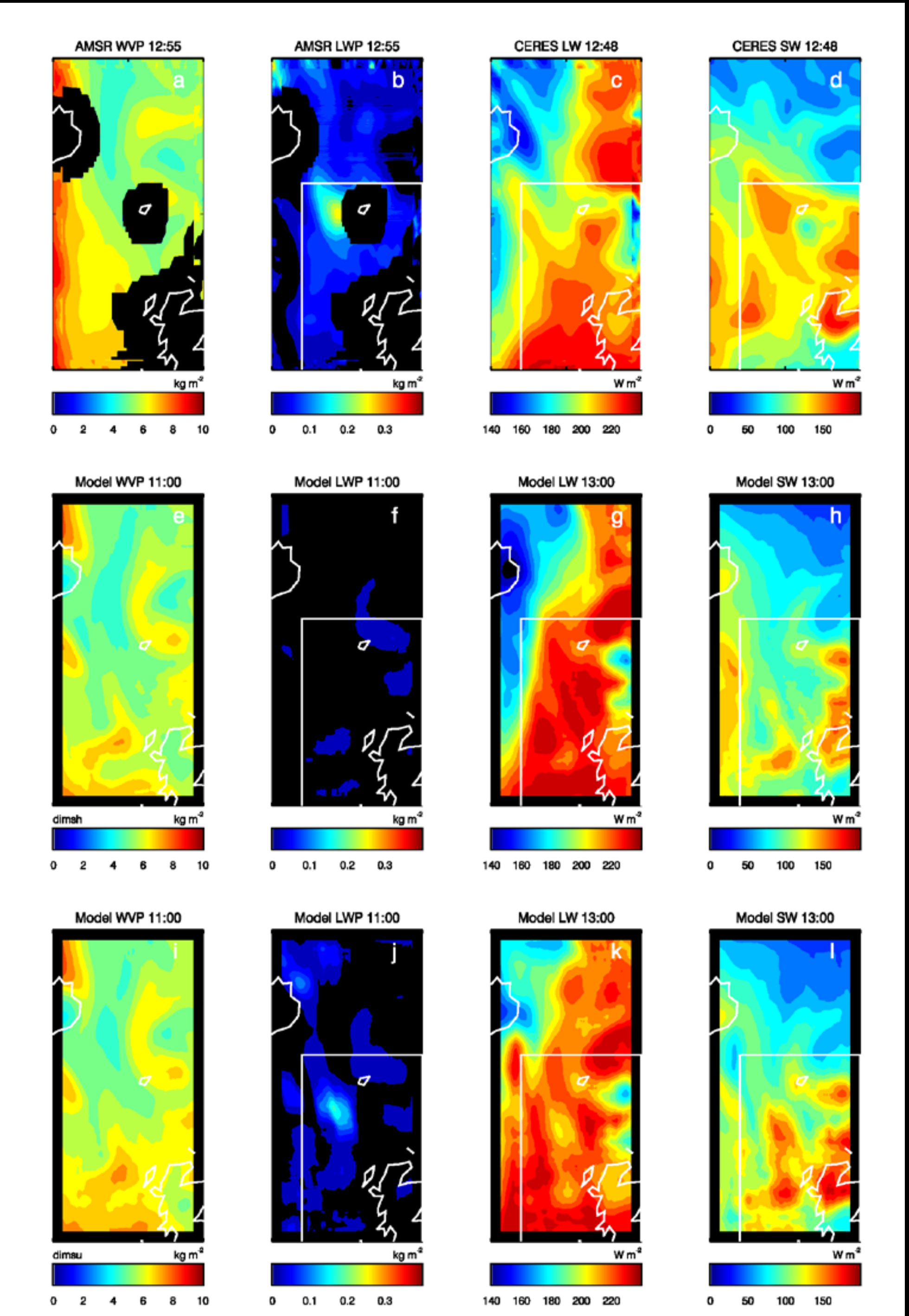




Experiment	Sh. dom. BL.	Tnuc=-18C	AcE=0.1	No ice	PSD	3dSmag
dims**h**						
dims**p**				✓		
dims**q**			✓			
dims**n**						✓
dims**k**	✓					
dims**i**	✓		✓			
dims**z**	✓	✓				
dims**y**	✓	✓	✓			
dims**u**	✓	✓	✓		✓	
dims**w**		✓	✓			✓



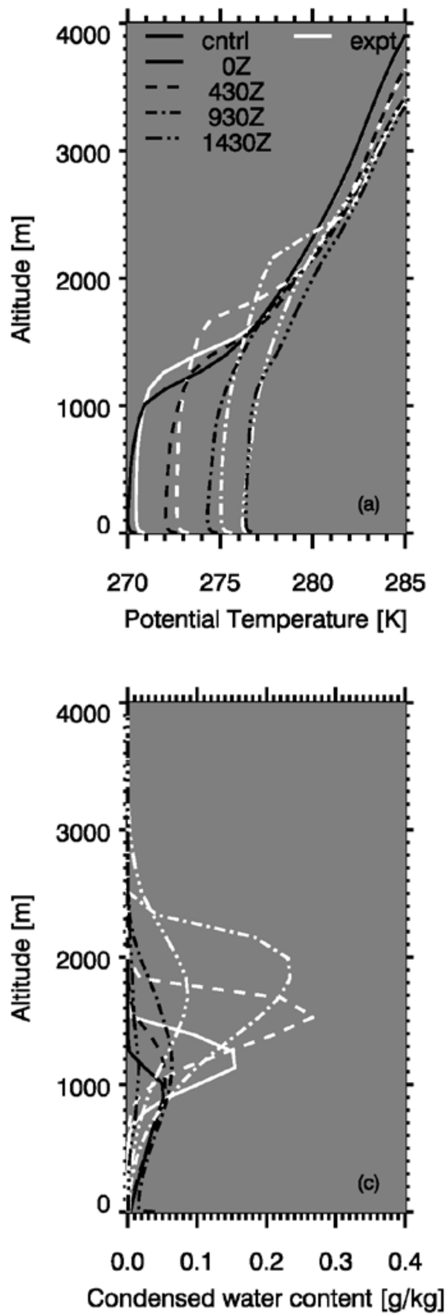
Experiment	Sh. dom. BL.	Tnuc=-18C	AcE=0.1	No ice	PSD	3dSmag
dims**h**						
dims**p**				✓		
dims**q**			✓			
dims**n**						✓
dims**k**	✓					
dims**i**	✓		✓			
dims**z**	✓	✓				
dims**y**	✓	✓	✓			
dims**u**	✓	✓	✓		✓	
dims**w**		✓	✓			✓



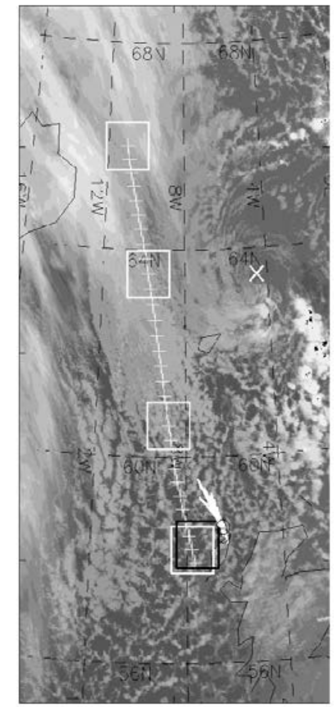
Microwave Obs

Control Model

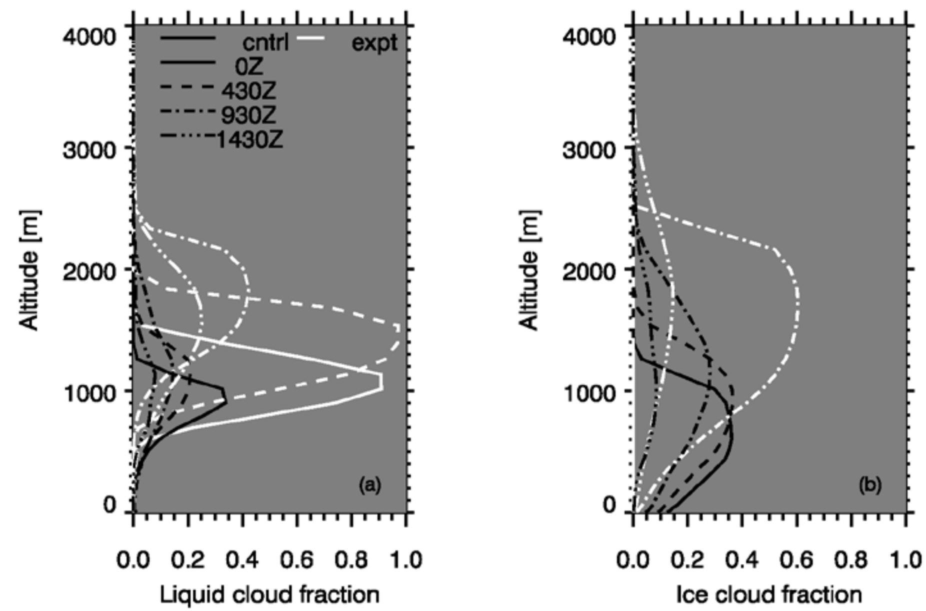
Modified Model
Sh dom BL
Thet=-18C
New PSD



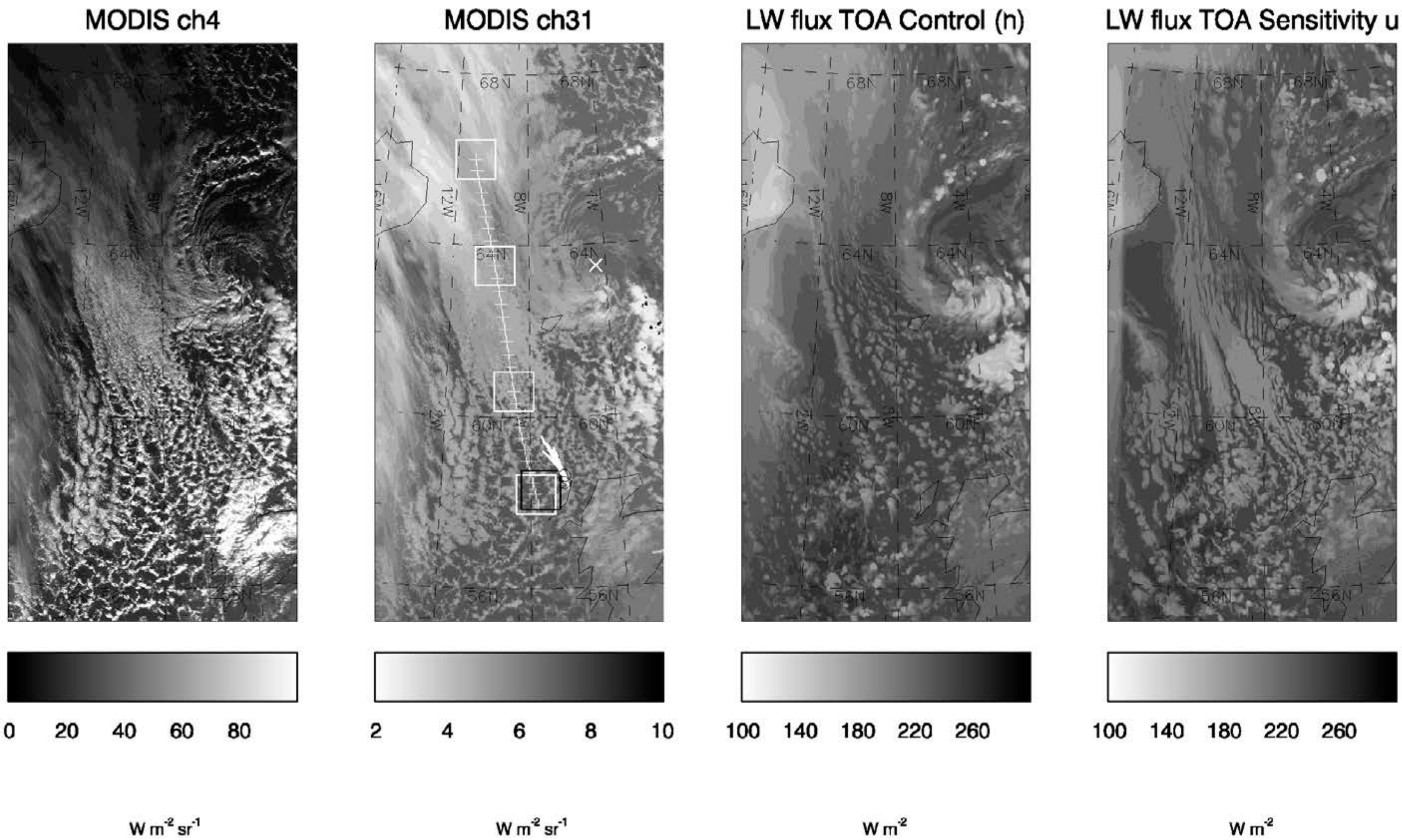
cntrl
expt
0Z
430Z
930Z
1430Z
Altitude [m]
Potential Temperature [K]
Total water [g/kg]
Condensed water content [g/kg]
RHwater
(a)
(b)
(c)
(d)



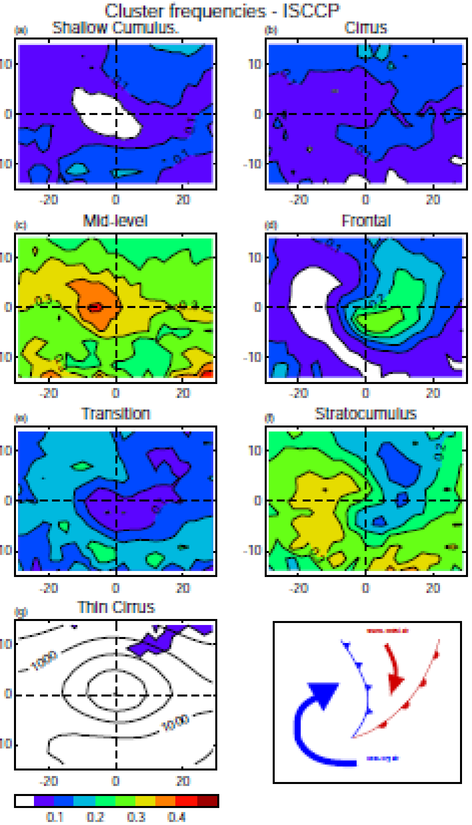
68N
64N
60N
56N
12W
8W
4W



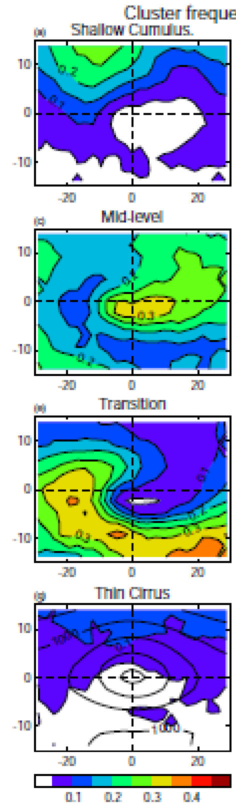
cntrl
expt
0Z
430Z
930Z
1430Z
Altitude [m]
Liquid cloud fraction
Ice cloud fraction
(a)
(b)


MODIS ch4
MODIS ch31
LW flux TOA Control (h)
LW flux TOA Sensitivity u
68N
64N
60N
56N
12W
8W
4W
0 20 40 60 80
2 4 6 8 10
100 140 180 220 260
100 140 180 220 260
W m-2 sr-1
W m-2 sr-1
W m-2
W m-2

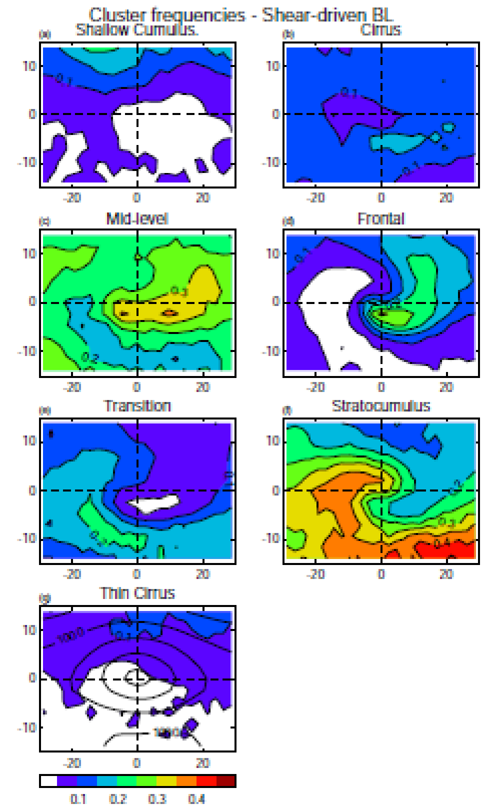
Effect in a climate model



Satellite



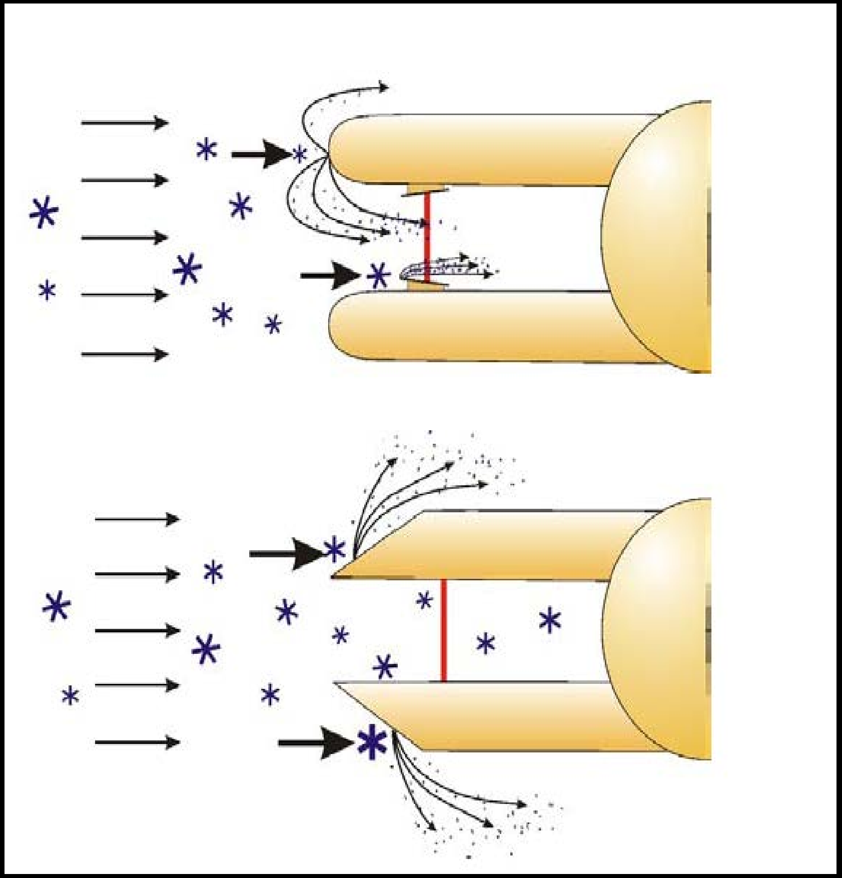
Old



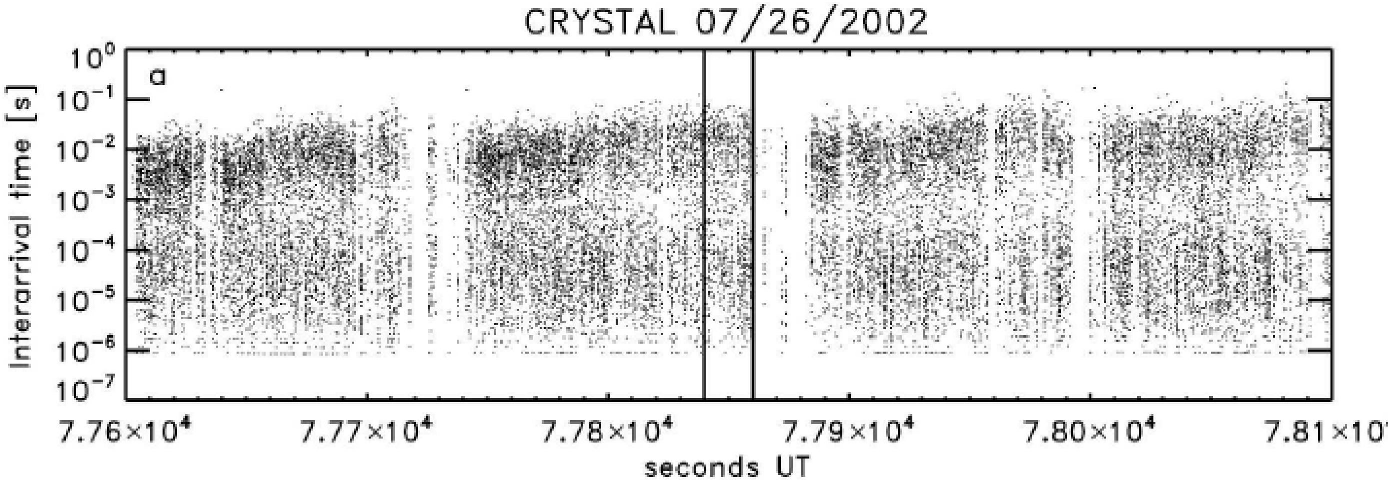
New

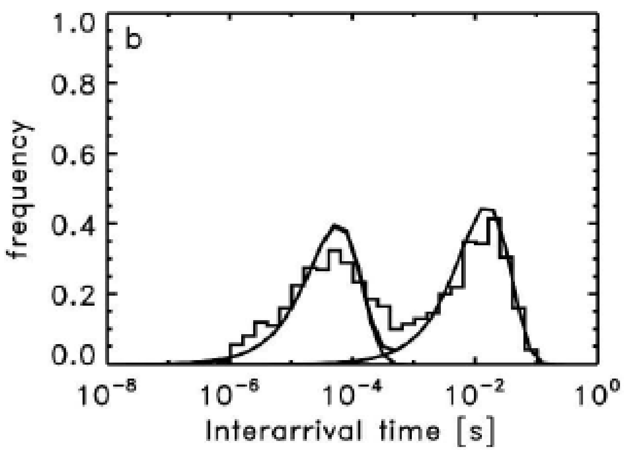
Bodas-Salcedo et al. 2012

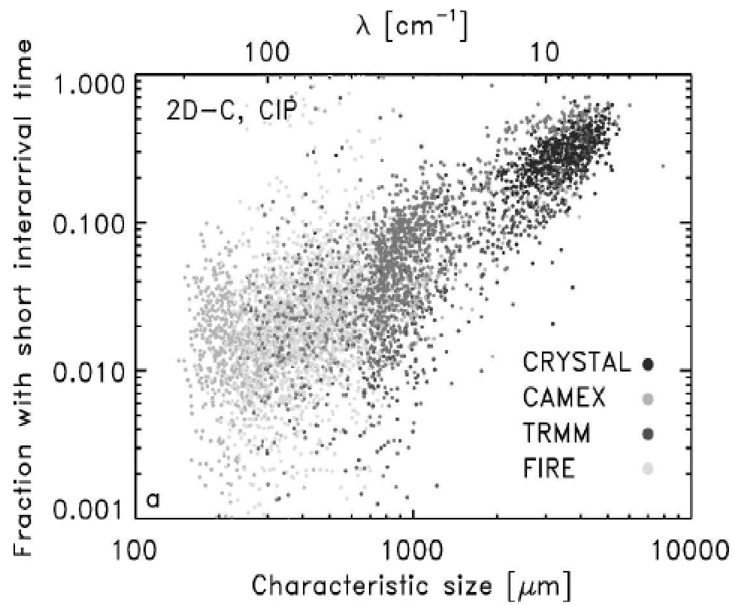
Aside part 1 - shattering

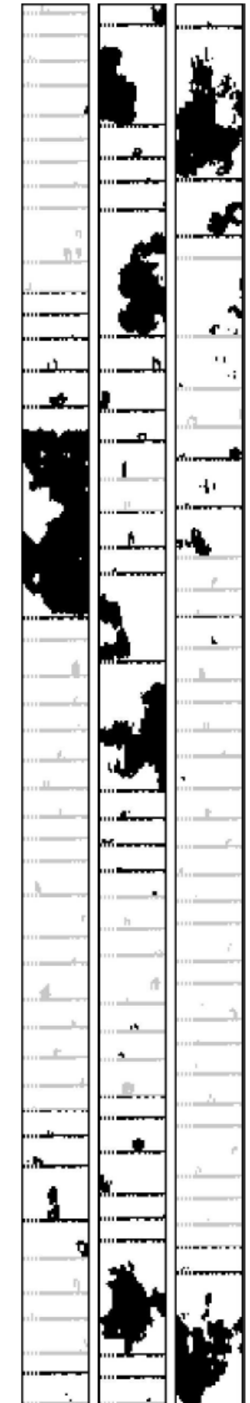


Korolev tips – from DMT site


CRYSTAL 07/26/2002
a
Interarrival time [s]
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
7.76×10^4
7.77×10^4
7.78×10^4
7.79×10^4
7.80×10^4
7.81×10^4
seconds UT


b
frequency
1.0
0.8
0.6
0.4
0.2
0.0
10^{-8}
10^{-6}
10^{-4}
10^{-2}
10^0
Interarrival time [s]


λ [cm^{-1}]
100
10
2D-C, CIP
Fraction with short interarrival time
1.000
0.100
0.010
0.001
a
CRYSTAL
CAMEX
TRMM
FIRE
100
1000
10000
Characteristic size [μm]



Mn=Σ $D^nN(D)$

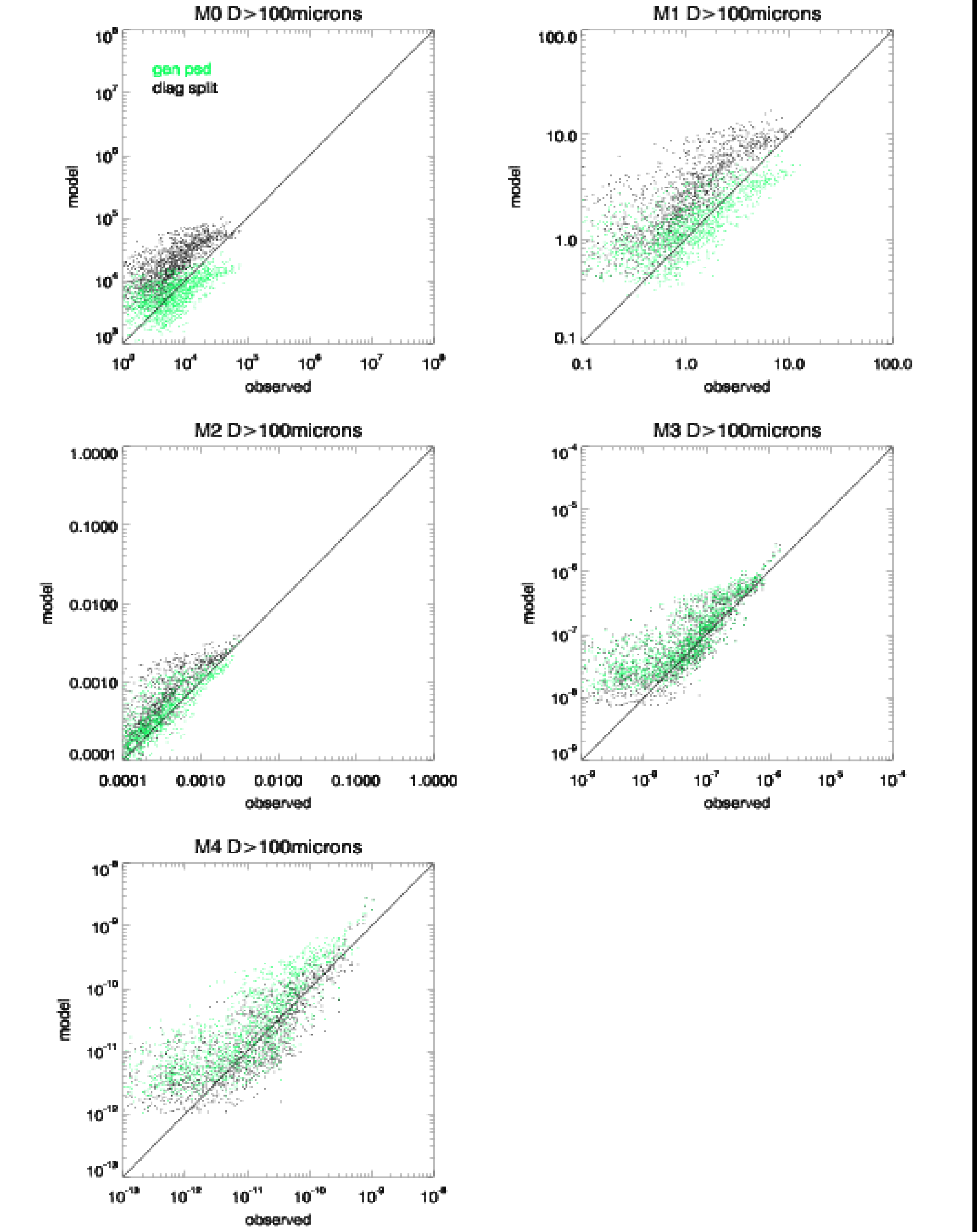
M0 = concentration

M1 proportional to diffusional growth

M2 proportional to IWC

M2+a bit proportional to snow flux

M4 proportional to radar reflectivity



Aside part 2 - mixed-phase

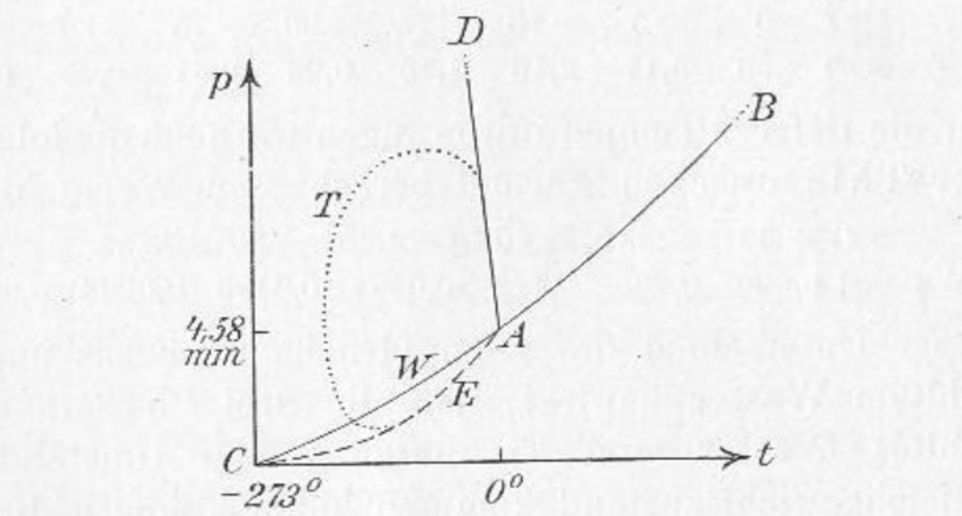


Fig. 17. Phasendiagramm des Wassers, schematisch.

The difference in vapour pressure above ice and supercooled liquid means that under no circumstance will the 3 phases of water come into equilibrium at the same temperature.

If the 3 phases are in contact (through the vapour phase) then the vapour pressure will adjust to a value between the saturated vapour pressure over ice and liquid. The consequence must be that diffusional growth of ice will occur at the same time as liquid evaporates. This will continue until the liquid is used up.

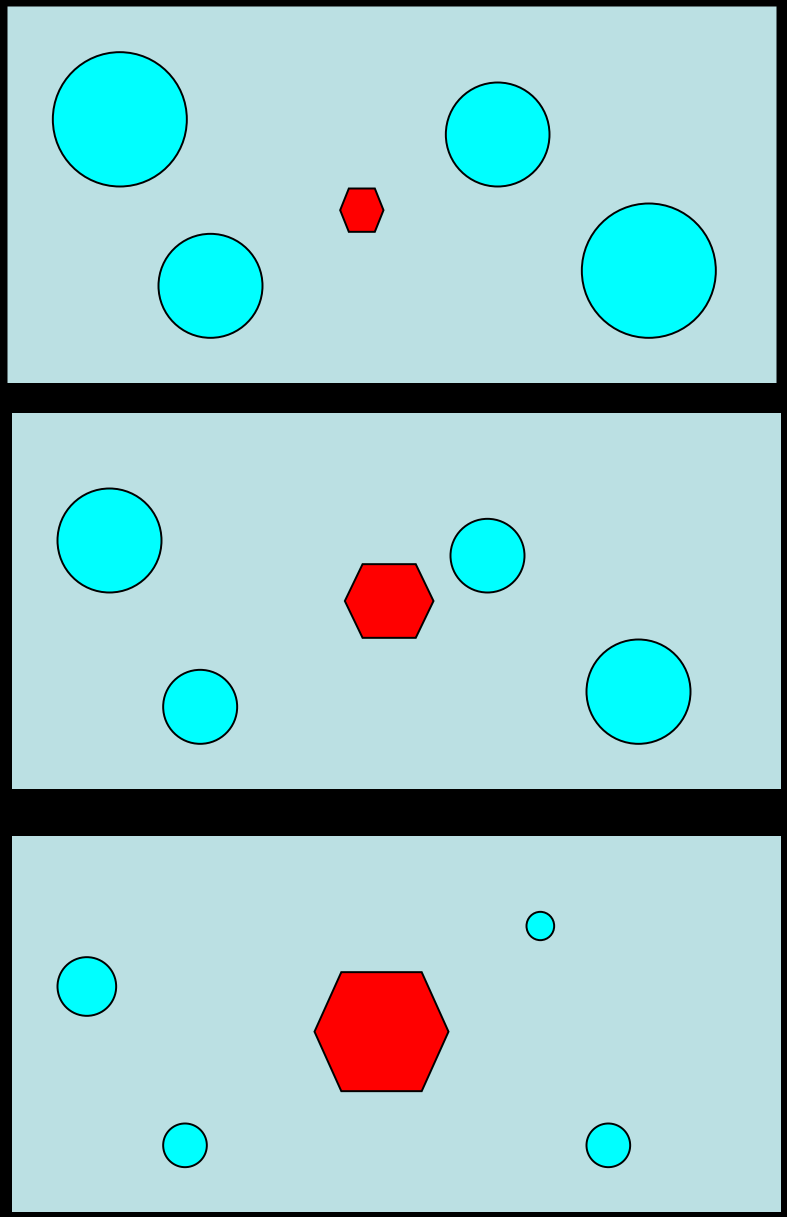
Wegener 1911

Bergeron 1935
On the physics of cloud and precipitation

- Review of precipitation formation ideas
  - Based on approach that clouds are colloids and precipitation is driven by colloidal instability.
- Recognizes that the result of ‘neighbouring elements of different phase’ has not been explored.
-

- Bergeron –

  'I thus presume that almost every real raindrop and all snowflakes originated around an ice crystal in the above mentioned way'



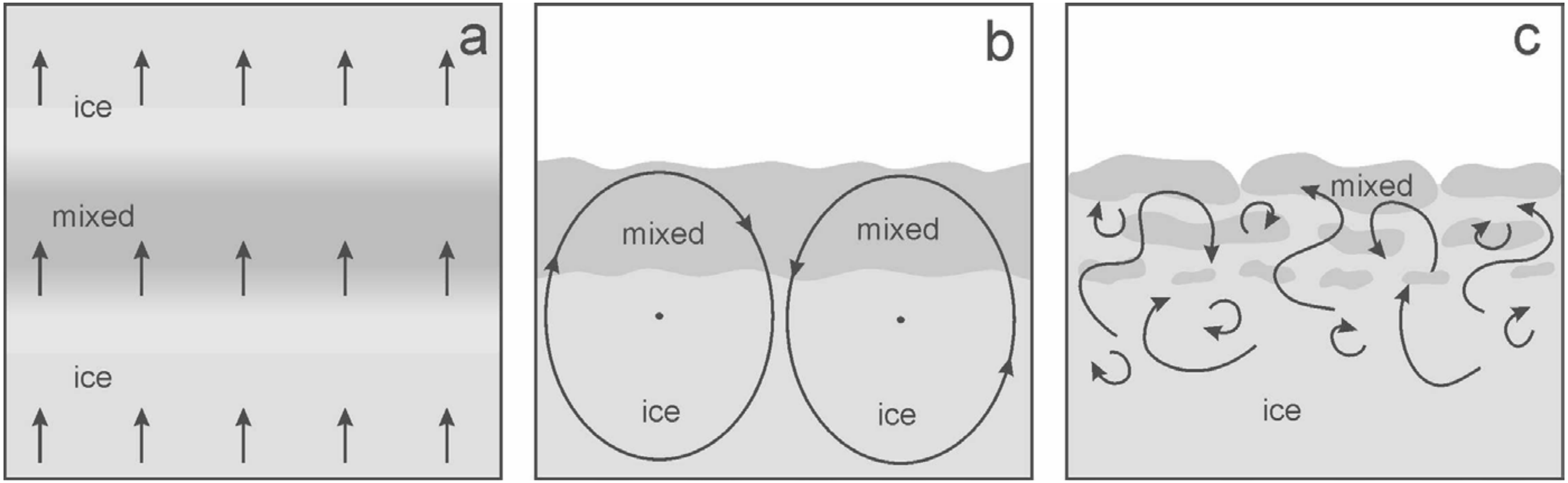
Dynamical effects

- The difference in vapour pressure above ice and supercooled liquid means that under no circumstance will the 3 phases of water come into equilibrium at the same temperature

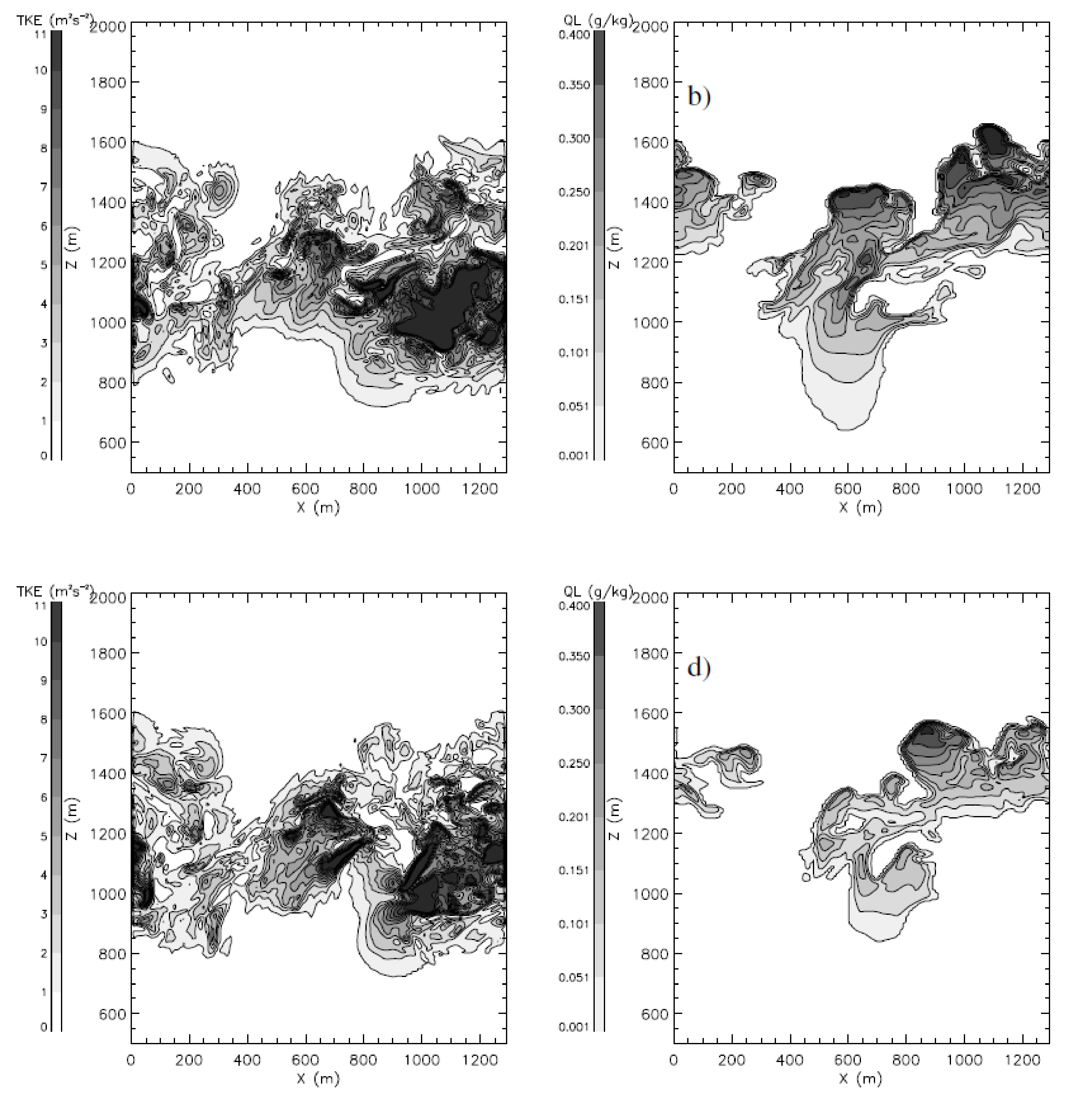
- Heymsfield 1977: Activate liquid water Uvert > threshold

- Mazin 1986:

- Korolev et al.



$$\frac{1}{1+S_i}\frac{\mathrm{d}S_i}{\mathrm{d}t} = a_i u - b_i B_0 M_1 S_i,$$



LEM
Δx = 10m
Δz = 5m
1.3x1.3x2.5km^3

T = -9, -6C

IWC=0.1 g/kg

Nice=1, 10, 100 L^{-1}

Shear:
10 m/s over 50m
15 m/s “ “

$$\frac{1}{1+S_i}\frac{\mathrm{d}S_i}{\mathrm{d}t} = a_i u - b_i B_0 M_1 S_i,$$

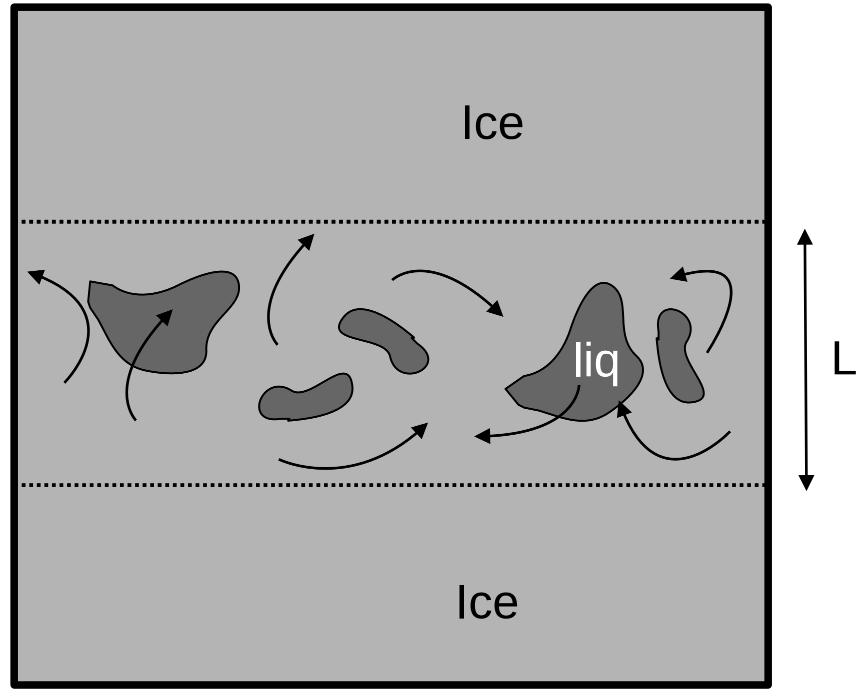
$$\mathrm{d}S_i = (-(B+C)S_i + CS_E)\mathrm{d}t + A\xi\mathrm{d}t$$

$$A = a_i \sigma_w \tau_d^{\frac{1}{2}}$$

$$\boxed{B = b_i B_0 M_1} \text{ and } \boxed{C = \left(\left(\tfrac{\epsilon}{L^2}\right)^{1/3}\right).}$$

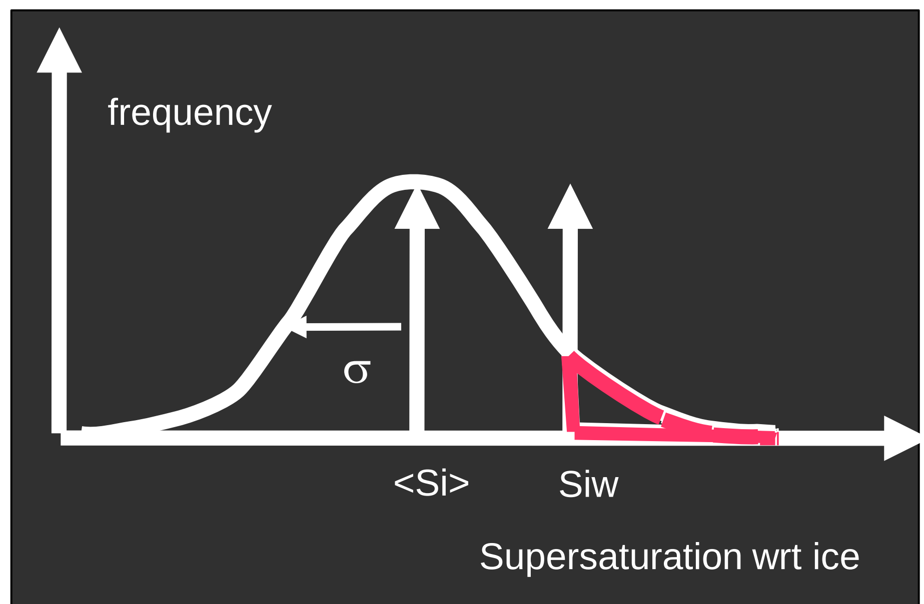
microphys

homogenisation

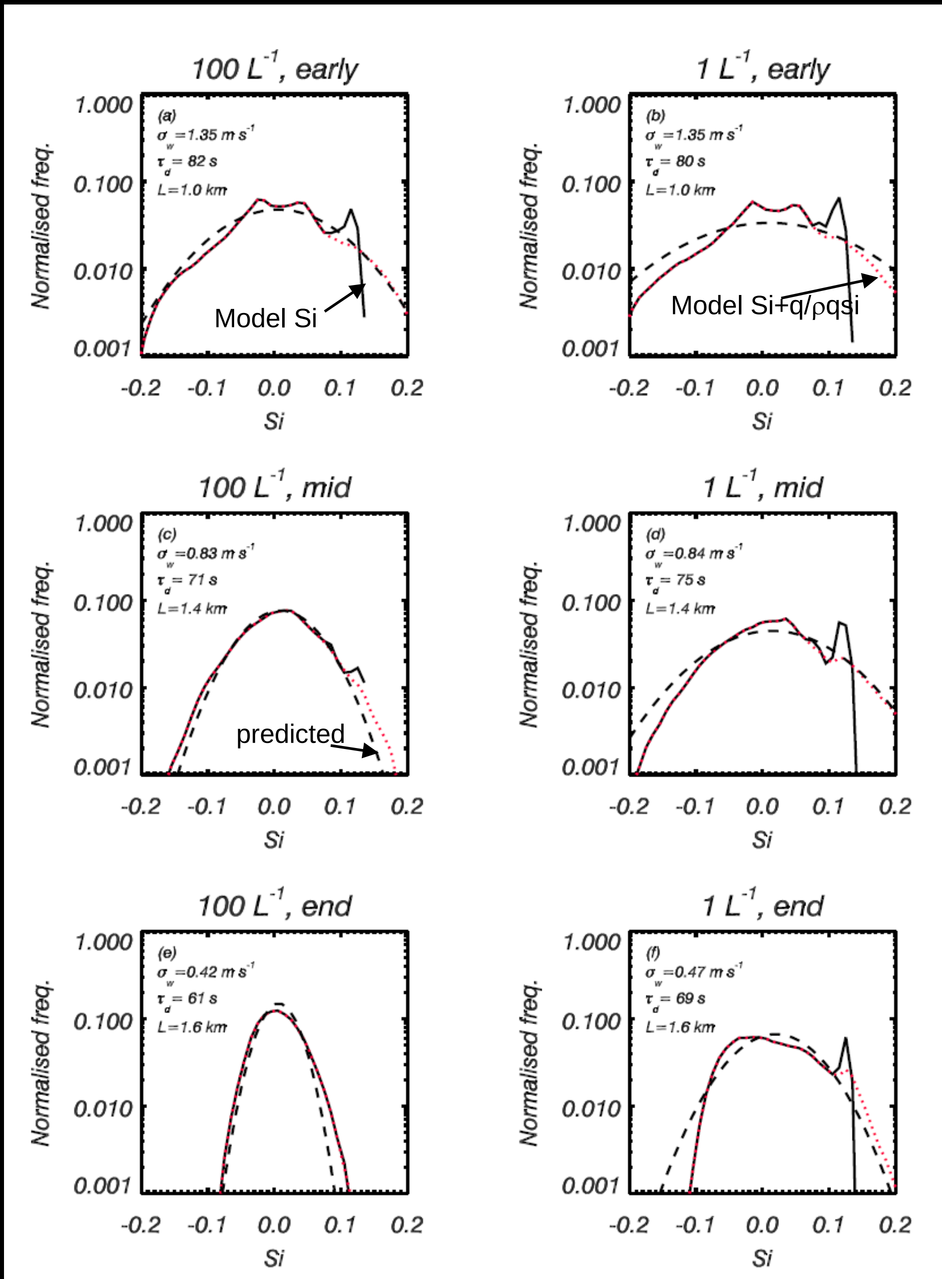


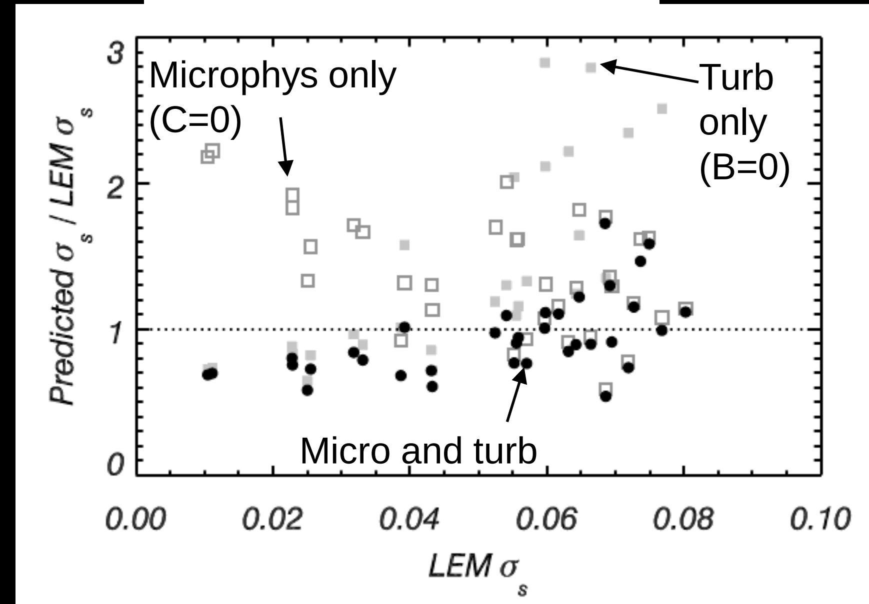
$$\langle S_i \rangle = S_E \frac{C}{B+C}$$

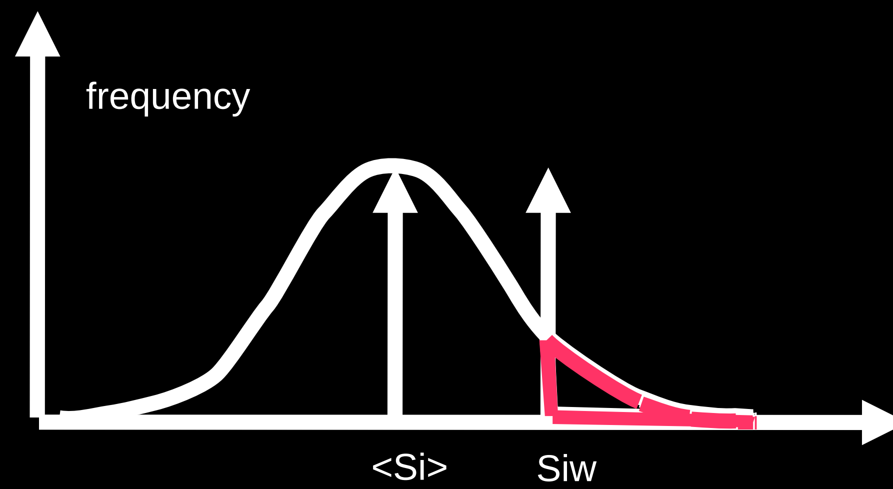
$$\sigma_S^2 = \frac{a_i^2 \sigma_w^2 \tau_d}{2\left(b_i B_0 M_1 + \left(\frac{\epsilon}{L^2}\right)^{1/3}\right)}.$$

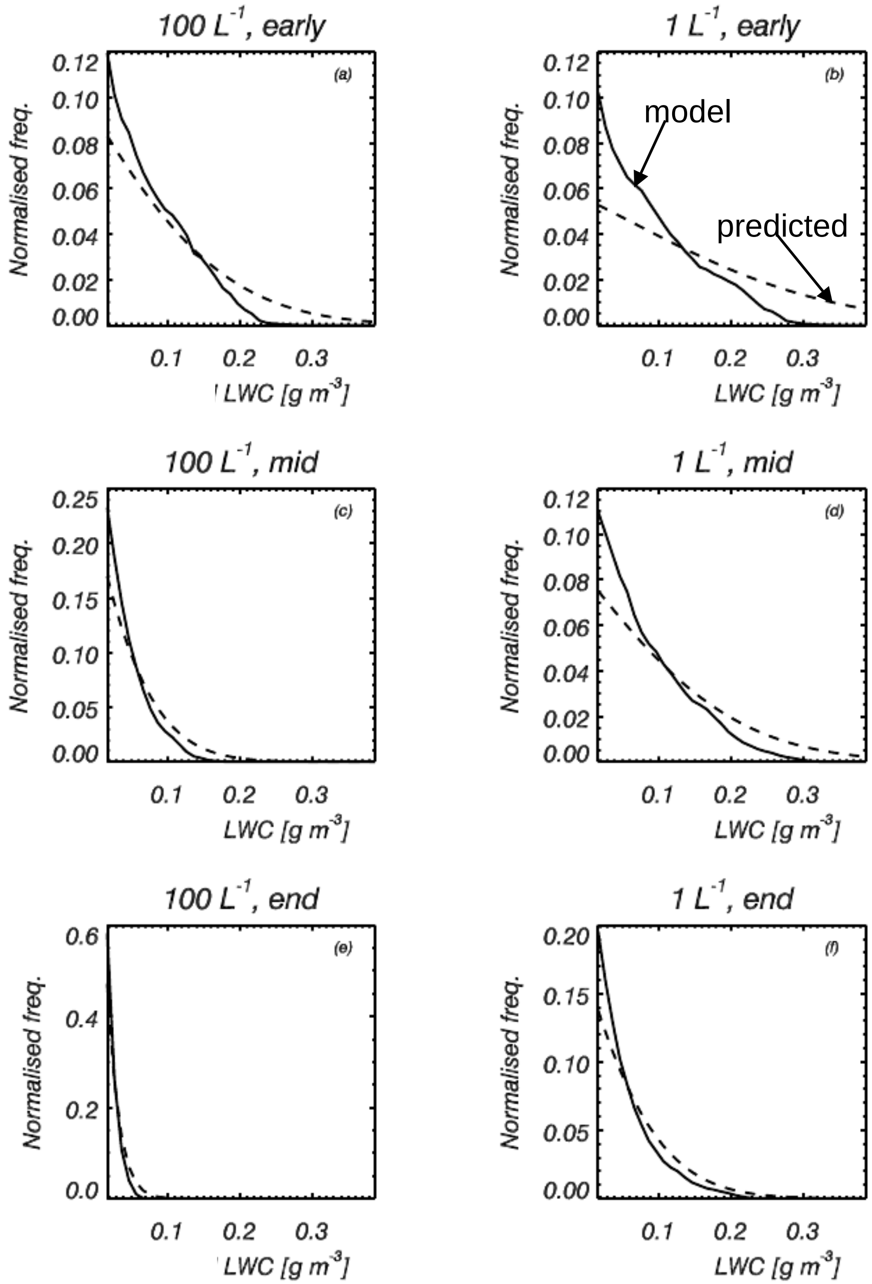


$$B = b_i B_0 M_1 \quad \text{and} \quad C = \left(\left(\frac{\epsilon}{L^2}\right)^{1/3}\right).$$

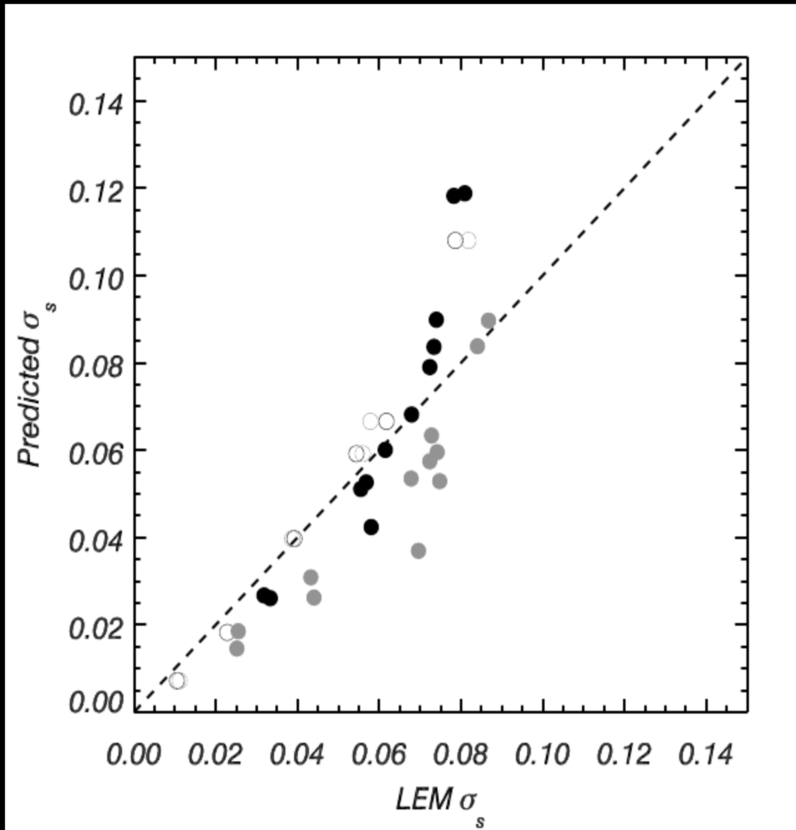


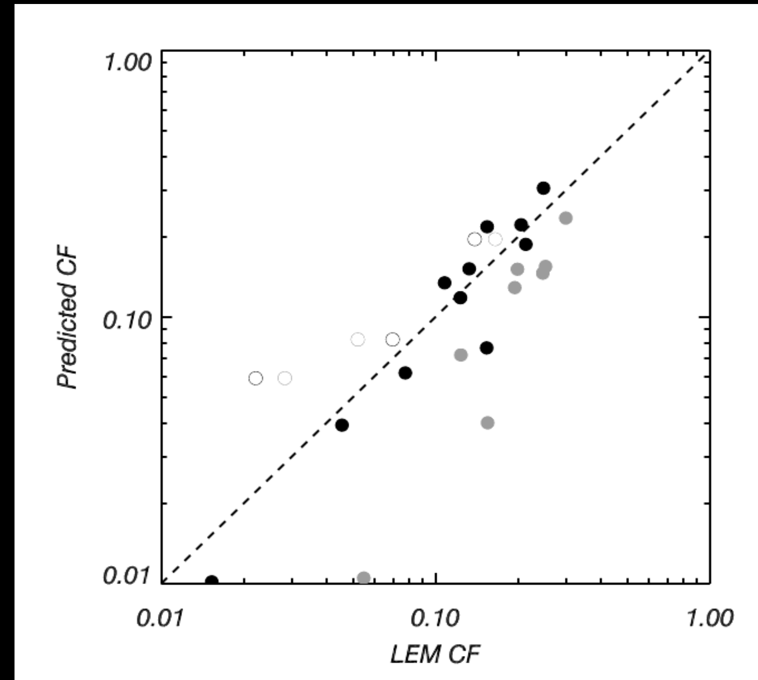


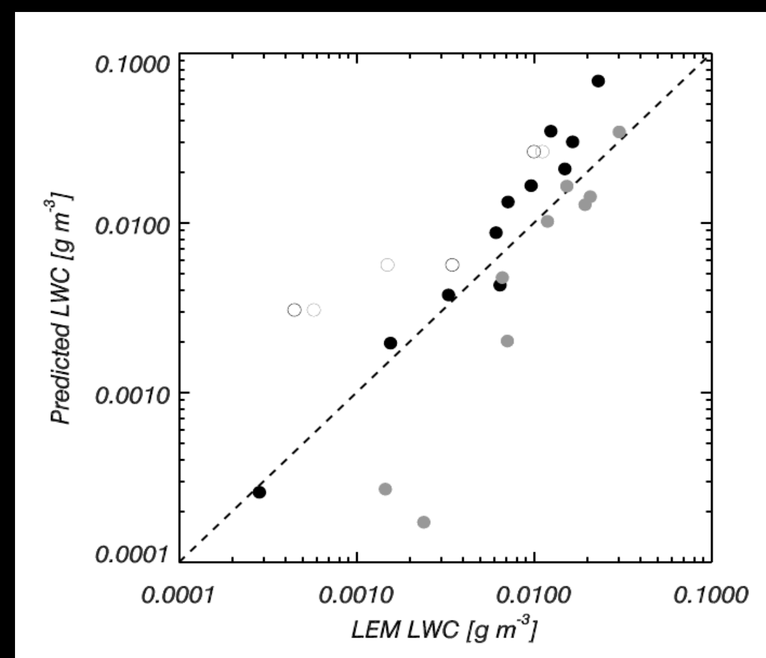




Supercooled liquid water distribution







Given turbulence characteristics (TKE, L) and ice cloud properties, we can estimate supercooled liquid cloud fraction (mixed-phase fraction) and the mean liquid water content of the turbulent region

General issues

Need to reassess treatment of mixed-phase – physically based subgrid treatment

Need to understand if existing PSDs representations are still adequate in the light of shattering

Need to re-examine het. ice nucleation representation – do we need to represent IN prognostically

...